(12)

AD A101877

Technical Report 476

20000728024

THE CONTRIBUTION OF HUMAN FACTORS IN MILITARY SYSTEM DEVELOPMENT: METHODOLOGICAL CONSIDERATIONS

Harold E. Price, Marco Fiorello, John C. Lowry
M. Gregory Smith, and Jerry S. Kidd
BioTechnology, Inc.

Prepared for
DOD HUMAN FACTORS ENGINEERING (HFE)
TECHNICAL ADVISORY GROUP (TAG)

U. S. Army
Research Institute for the Behavioral and Social Sciences

OTHER SUPPORTING ORGANIZATIONS

July 1980

U. S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency under the Jurisdiction of the Deputy Chief of Staff for Personnel

FRANKLIN A. HART
Colonel, US Army
Commander

JOSEPH ZEIDNER
Technical Director

NOTICES

(18) ARI (19)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report 476 (19) TR-476	2. GOVT ACCESSION NO.: AD-A101 877
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): (6) THE CONTRIBUTION OF HUMAN FACTORS IN MILITARY SYSTEM DEVELOPMENT: Methodological Considerations.	5. TYPE OF REPORT & PERIOD COVERED: (9) Final Report, September 1979 – July 1980
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) Harold E. Price, Marco Fiorello, John C. Lowry, M. Gregory Smith and Jerry S. Kidd	8. CONTRACT OR GRANT NUMBER(s): (15) MDA 903-79-C-0553
9. PERFORMING ORGANIZATION NAME AND ADDRESS: BioTechnology, Inc., 3027 Rosemary Lane, Falls Church, VA 22042	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: (16) 2Q162722A765
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Research Institute for the Behavioral and Social Sciences, 5001 Eisenhower Ave., Alexandria, VA 22333	12. REPORT DATE: (11) July 1980
	13. NUMBER OF PAGES: 291
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 295	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for open release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

A companion research note (ARI RN-80-23) is available through the Defense Technical Information Center. Title: "Department of Defense and Service Requirements for Human Factors R&D in the Military System Acquisition Process."

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Human Factors
Military System Development
Cost-Benefit Analysis
Human Engineering
System Metrics

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document reports on an effort to determine (a) the conceptual basis for human factors contributions to military system development and (b) the feasibility of an impact assessment methodology to measure the value of human factors R&D in system development. For these purposes, two parallel analytic processes were implemented.

(continued)

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED 058050

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

One analytic process provided the conceptual basis for human factors in military system development. First, a rationale for human factors contributions and products was prepared. This rationale was further supported by policy documentation containing requirements for human factors R&D. The second analytic process provided the basis for evaluating human factors contributions. A review of cost-benefit analysis techniques applicable to human factors was performed together with a derivation of measurement metrics. These efforts resulted in a framework for performance of impact assessment and a determination that it is a feasible methodology for application to evaluations of human factors contributions to military system development.

This technical report provides recommendations for further refinement and validation of impact assessment in the measurement of the value of human factors efforts and products. Recommendations for developing human factors impact assessment handbooks are also provided.

Technical Report 476

THE CONTRIBUTION OF HUMAN FACTORS IN MILITARY SYSTEM DEVELOPMENT: METHODOLOGICAL CONSIDERATIONS

Harold E. Price, Marco Fiorello, John C. Lowry
M. Gregory Smith, and Jerry S. Kidd
BioTechnology, Inc.

Prepared for
DOD HUMAN FACTORS ENGINEERING (HFE)
TECHNICAL ADVISORY GROUP (TAG)

Submitted by:
Stanley M. Halpin, Acting Chief
HUMAN FACTORS TECHNICAL AREA

Approved by:
Edgar M. Johnson, Director
ORGANIZATIONS AND SYSTEMS
RESEARCH LABORATORY

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
5001 Eisenhower Avenue, Alexandria, Virginia 22333

Office, Deputy Chief of Staff for Personnel
Department of the Army

July 1980

Army Project Number
2Q162722A765

Systems Requirements and Operations

ARI Research Reports and Technical Reports are intended for sponsors of R&D tasks and for other research and military agencies. Any findings ready for implementation at the time of publication are presented in the last part of the Brief. Upon completion of a major phase of the task, formal recommendations for official action normally are conveyed to appropriate military agencies by briefing or Disposition Form.

FOREWORD

The Human Factors Technical Area of the Army Research Institute (ARI) is concerned with human resource demands of increasingly complex battlefield systems used to acquire, transmit, process, disseminate, and utilize information. This increased complexity places great demands upon the operator interacting with the machine system. Research in this area focuses on human performance problems related to interactions within command and control centers as well as issues of system development. The research program includes both technology base and advanced development research as well as a limited amount of technical advisory service (TAS) to Army agencies and activities. The general purpose of TAS is to provide immediate consulting assistance in meeting short-term priority requirements.

One area of special interest involves the development of estimates for the contributions of human factors in military system development. The inquiry into the topic resulted from a tri-service committee decision to investigate the possibility of providing system designers/managers with evidence of the value of human factors to compare with other pertinent information from engineers, operations research analysts and system analysts. This initial report emphasizes the methodological considerations of such an undertaking and creates a foundation for implementation of such an effort by system personnel.

The following individuals contributed to this effort: Dr. Edgar M. Johnson and Dr. Thomas M. Granda (ARI); Mr. Paul Linton (Naval Air Development Center); Mr. John L. Miles, Jr. (Human Engineering Laboratory); Dr. Donald A. Topmiller (USAF Aerospace Medical Research Laboratory); and Dr. Alfred R. Fregly (Air Force Office of Scientific Research).

Joseph Zeidner

JOSEPH ZEIDNER
Technical Director

A

THE CONTRIBUTION OF HUMAN FACTORS IN MILITARY SYSTEM DEVELOPMENT; METHODOLOGICAL CONSIDERATIONS.

BRIEF

Requirement:

To determine the conceptual basis for human factors contributions to military system acquisition and development. Given this conceptual basis, to determine a feasible method for evaluating the contribution of human factors.

Procedure:

Two parallel analytic processes were used to determine a conceptual basis and feasible methodology for assessing the contribution of human factors in system development.

- A first analytic process involved the development of a rationale for human factors in system development, followed by a determination of the existing basis for human factors R&D (ranging from formal DOD requirements to informal documentation). This culminated in a determination of the conceptual basis for identifying human factors contributions, through analysis of human factors principal products, system-specific efforts, and technology base.
- A second analytic process was undertaken to determine a feasible method for evaluating human factors contributions, including the identification of metrics for measuring the value of human factors. Concurrent with this, a review of cost-benefit analysis techniques was conducted. Out of these efforts, an impact assessment methodology emerged as the most feasible methodology for measuring the value of human factors contributions in military system development.

Product:

Several items worthy of note include: the development of a conceptual basis in which specific human factors efforts and products for each phase of system development were defined; a preliminary set of measurement metrics were developed; the framework of an impact assessment methodology for evaluation of human factors R&D was developed; and an impact assessment vocabulary hierarchy, tailored to human factors, was specified (i.e., impact areas, metrics, and empirical measures).

Utilization:

The conceptual basis for human factors, in conjunction with the impact assessment methodology, can be used to advantage by practitioners who wish to determine the contributions of human factors R&D to military system development. Although the methodology requires additional refinement, and validation through case examples, the present approach can be implemented.

CONTENTS

		Page
Chapter 1	Introduction	1-1
	Project Objectives	1-1
	The Boundaries of Human Factors	1-2
	Definition of Human Factors	1-2
	Classification of Human Factors RDT&E	1-4
	Scope of Human Factors	1-4
	The Integration of Human Factors and Military System Development	1-7
	Overview of the Project	1-9
	Human Factors in Military Systems	1-12
	The Measurement of Human Factors Contributions	1-13
	The Concept of Impact Areas	1-17
	Summary and Synthesis	1-19
	References	1-22
Chapter 2	A Rationale for the Value of Human Factors in System Development	2-1
	Historical Background of Military Human Factors	2-2
	Military System Complexity and Human Factors	2-6
	Human Error, Human Factors, and System Effectiveness	2-10
	Optimal Manned Systems--The Compatibility Factor	2-18
	Unique Human Capabilities	2-19
	Human Limitations	2-20
	Compatibility and User Acceptance	2-21
	Are There Opportunities for Human Factors in System Development?	2-24
	Do We Use What We Know About Human Factors?	2-26
	Are Human Factors Contributions Affordable?	2-32
	Conclusion	2-34
	References	2-36

CONTENTS (continued)

	Page
Chapter 3 Identification of the Contribution of Human Factors in System Development	3-1
Human Factors R&D: The Existing Basis in System Acquisition	3-4
The Major System Acquisition Process	3-4
Revised Department of Defense 5000 Series Directives	3-8
Formal and Informal Requirements for Human Factors R&D at the Service Level	3-12
Human Factors R&D: Specific Efforts for Each System Development Phase	3-13
Mission Analysis Phase Human Factors	3-21
Human Factors Efforts and System Development Activities During Mission Analysis	3-22
Content of the Role of Man Statement	3-27
Mission Analysis Phase: Example of Human Factors Contributions	3-30
Concept Development Phase Human Factors	3-33
Human Factors Efforts and System Development Activities During Concept Development	3-33
Content of the Allocation of Functions to Man Statement as Part of the Decision Coordinating Paper	3-37
Concept Development Phase: Example of Human Factors Contributions	3-40
Demonstration/Validation Phase Human Factors	3-42
Human Factors Efforts and System Development Activities During Demonstration/Validation	3-43
Content of the Task Analysis and Human Engineering Requirements Product	3-50
Demonstration/Validation Phase: Example of Human Factors Contribution	3-55
Full-Scale Development Phase Human Factors	3-58
Human Factors Efforts and System Development Activities During Full-Scale Development	3-59

CONTENTS (continued)

Page

Content of the Optimal Man-Machine Interface Design 3-63

Full-Scale Development Phase: Two Examples of Human Factors Contributions 3-68

Production and Deployment Phase Human Factors 3-71

Human Factors Efforts and System Development Activities During Production and Deployment . . . 3-72

References 3-76

Chapter 4 Human Factors RDT&E in the Technology Base and the Contribution to System Development . . . 4-1

R&D Funding Categories 4-4

Tracking Research to Utilization 4-5

Illustrations of Contributions from the Technology Base to Specific System Development 4-8

References 4-20

Chapter 5 Deriving Metrics for Measuring the Value of Human Factors in Military Systems Development. . 5-5

Background 5-2

Identifying and Defining Metrics 5-4

Literature Search and Data Base System 5-6

Screening and Selection Process 5-8

Derivation of Metrics 5-8

Impact Areas, Metrics, and Related Measures 5-13

Capability Impacts 5-13

Cost Impacts 5-14

Compatibility Impacts 5-16

Summary 5-21

References 5-22

Chapter 6 Methodology for Evaluating Human Factors Impacts in Military Systems Development 6-1

Human Factors Impact Assessment: Related Concepts, Limitations, and Considerations 6-2

CONTENTS (continued)

	Page
Methodological and Data Limitations	6-5
Considerations for Human Factors Practitioners	6-8
Rigor vs. Broad-Based Analysis	6-11
Human Factors Impact Assessment: Conceptual Framework	6-13
Basic Framework and Steps	6-13
Techniques for Estimating Impacts: Classification and Selection	6-32
Future Steps	6-38
References	6-40
Chapter 7 Conclusions and Recommendations	7-1
Appendix A A Rationale and Precedent for Establishing the Principal Human Factors Products During System Development	A-1
Appendix B Derived Vocabulary List of Human Factors Metrics	B-1
Appendix C Examples of Human Factors Efforts Related to System Development Products and Metrics . .	C-1

EXHIBITS

Exhibit		Page
1-1	DOD Definitions	1-3
1-2	Classification of Human Factors RDT&E	1-5
1-3	Hypothetical Distribution of System Development Outcomes With and Without Optimum Human Factors Participation	1-7
1-4	Relationship of the Major Efforts of the Study	1-10
1-5	Relationship of System Attributes to the Choice of Impact Analysis Techniques	1-20
2-1	Development of MIL-STD-1472	2-4
2-2	Cockpit Space and Information Requirements for Several Navy Aircraft Weapon Systems	2-8
2-3	Trend of Accident Rates for Typical Navy Aircraft and the AV-8A Harrier	2-9
2-4	A Trident Missile Test at Cape Canaveral	2-12
2-5	Effect of Human and Equipment Reliability on System Reliability, $R_E \times R_H = R_S$	2-14
2-6	Typical Sources for Attribution of Human Error	2-15
2-7	Human Engineering Problems in Weapon Systems	2-25
2-8	Human Factors Deficiencies Report for Several Navy Aircraft Weapon Systems	2-30
3-1	Principal Human Factors Products for Major System Development Phases	3-3
3-2	The Activities and Decision Points of OMB's Circular No. A-109 Major System Acquisition Cycle	3-5
3-3	A Comparison of Names Used for the Major System Acquisition Model	3-7
3-4	The Phases of the Military's Major System Acquisition Model	3-9
3-5	Specific Human Factors Efforts and Products for Each Military System Development Phase	3-15

EXHIBITS (Continued)

Exhibit		Page
3-6	Specific Human Factors Efforts During the Mission Analysis Phase (0.)	3-23
3-7	Specific Human Factors Efforts During the Concept Development Phase (1.)	3-34
3-8	Specific Human Factors Efforts During the Demonstration/Validation Phase (2.)	3-44
3-9	Specific Human Factors Efforts During the Full-Scale Development Phase (3.)	3-60
3-10	Specific Human Factors Efforts During Production and Deployment (4.)	3-73
4-1	Areas of Opportunity for Human Factors R&D in the Technology Base to Contribute to Military System Development	4-2
4-2	The Classification System for Human Factors R&D	4-3
5-1	Hierarchical Relationship of Impact Areas, Metrics, and Empirical Measures	5-5
5-2	Sample of System-Related Terms and Associated Dimensions (Unit of Measure)	5-9
5-3	Preliminary Metrics Derived from the Literature	5-10
5-4	Sample Relationship Among Selected System Related Metrics and Empirical Measures (As Found in the Literature)	5-11
5-5	System Life Cycle Cost Impact Area for a Weapon System	5-12
6-1	Simple Illustration of an Impact Assessment Matrix	6-4
6-2	Impact Assessment Framework	6-14
6-3	Goal Relevance Tree Hierarchy of Goals - Objectives - Criteria	6-16
6-4	Input-Output Matrix for Problem Formulation	6-18

EXHIBITS (continued)

Exhibit		Page
6-5	Candidate Models and Techniques for Human Factors R&D Cost Benefit/Impact Assessments (sample only)	6-34
6-6	Models and Research Techniques Useful in Human Factors Analysis in Relation to the Phases of System Development and Principal Human Factors and Products	6-39
C-1	Illustrations of Metrics Used to Link Human Factors Products and Impact Areas	C-2

CHAPTER 1
INTRODUCTION

Project Objectives

In a sense, the present project represents an attempt to confront an irony: while the sophistication of military systems is increasing, the attention paid to the capabilities and limitations of those people who must operate and maintain them has not been increasing. The arena in which this irony can be most effectively confronted is the process of military system development.

The overriding objective of the present project is to enhance the value of all U.S. military systems. The route to that objective that is paramount for the present effort is the assurance that the human factors contribution to military system development is timely, of an appropriate quantity, and, most explicitly, that it is of high quality.

In another sense, then, we are concerned with the quality control of what is widely regarded as an essential ingredient in the overall military system development effort. If we follow our own precepts, however, we know that quality assurance depends on accurate feedback and that feedback, in turn, depends on evaluation.

Consequently, the key ingredient in achieving the broader objective is the establishment of the means to evaluate the contribution of human factors to military system development. It is the construction of that key ingredient that has been the immediate objective of the project.

The Boundaries of Human Factors

In order to identify and measure the contribution of human factors it is necessary to define human factors. It is also appropriate not only to provide a definition but also to provide some classification of human factors R&D and a discussion of its scope, for reasons that should become clear shortly. Collectively these terms will be called the "Boundaries of Human Factors Research and Development." Each of these boundaries will be briefly described below.

Definition of Human Factors

A comprehensive definition of human factors R&D that is used by DOD and all services does not exist. This is not to suggest that we do not already know essentially what human factors is, but rather to suggest that we are not interested in a precise, academic definition of human factors for this study.

For the purposes of this report, we know that human factors is one of the four categories of people-related research funded as part of the RDT&E budget of the DOD. These four categories have been defined by the Military Assistant for Training and Personnel Technology in the Office of the Under Secretary of Defense for Research and Engineering in some recent briefing materials. These definitions are provided in Exhibit 1-1. Another DOD definition of human factors is contained in the Technology Coordination Paper for FY 1978 (Department of Defense, 1979):

> Human factors technology is concerned with the design, development, evaluation, and deployment of manned systems so that human operators would be able to operate and maintain military systems at their optimum performance level. This includes the systematic investigation of how the design of a person's job and the tools that are provided affect his capacity to do a job.

Exhibit 1-1

DOD Definitions*

● **HUMAN FACTORS–** Development of improved methods and technologies for the analysis, design, and evaluation of equipment/systems for safer and more efficient operation and maintenance.
● **PERSONNEL & MANPOWER–** Development of techniques/methods for utilizing available personnel resources through improved selection, job assignment, organizational analysis, and management techniques to meet combat available and projected force needs.
● **EDUCATION & TRAINING–** Development of educational/training methods and media for managing, designing, and evaluating new generation instructional systems for military applications.
● **SIMULATION & TRAINING DEVICES–** Development of cost-effective training equipment and technology that produce the needed performance for operation and maintenance of military systems.

*This chart is from a brief provided by the Military Assistant for Training and Personnel Technology (OUSDR&E).

This DOD definition perhaps defines the boundaries of human factors in terms of its technical domain; but metrics for determining the value of human factors and costs for assessing the affordability of human factors need to be more adequately defined. Concerning these two points, a few statements can be made that are useful in shaping this important definition:

- Metrics for measuring the value of human factors must include measures of both system capability and cost. We will also define the area of man-system compatibility as a category of metrics. Further, human factors efforts on products must also relate to system performance.

- Affordability of human factors must be assessed not only in terms of dollars spent but also in terms of cost avoidance (through reduced selection, manpower, or training requirements).
- User acceptance must be part of the value of human factors. Changes in personnel attitude not only contribute to more effective use of the equipment or system, but may have long-term effects on issues such as attrition and retention.

In summary, there seems to be a consensus that human factors includes effective integration of man's role and performance into system operation and maintenance.

Classification of Human Factors RDT&E

Another boundary of human factors that is important is the classification of the work. Again, DOD has standardized this dimension for RDT&E. Exhibit 1-2 shows the three classifications for human factors work and gives some indication of what is included in each class (Fiorello et al., 1979). A cursory examination of these classes suggests that they may correspond roughly to categories of R&D funding (6.1, 6.2, and 6.3), at least with respect to the technology base, but this possibility must be explored in more detail (see Chapter 4).

Scope of Human Factors

Perhaps the most limiting boundary of human factors has been the scope of its integration into the system development process. In brief, there has been precious little utilization of human factors in the early phases of system acquisition, particularly in the Mission Analysis and Concept Development Phases. There has been more utilization in the Demonstration/Validation Phase;

and by far the greatest utilization has occurred in the Full-Scale Development Phase, where the traditional human engineering or man-machine interface design occurs. Perhaps the reason for the lack of human factors in the earlier phases of system development is the lack of recognition that there is both a product and a payoff to be had during these early phases.

Exhibit 1-2

Classification of Human Factors RDT&E

- **Human Related Studies**

  "What are the capabilities and limitations of operators and maintainers of systems/subsystems?" Emphasis is on increasing our state of knowledge concerning humans' operational performance. Included are data, performance methods relevant to physical characteristics, sensory and motor capabilities, and human information processing.

- **Human-Machine Related Studies**

  "How do we allocate functions between people and equipment?" This is often termed "subsystem" related because it concerns the design of a specific man-machine relationship. Included are efforts dealing with computer-aided methods for human engineering, workload measurement techniques, designing for maintainability, control and display design, and workspace layout.

- **Human-Machine-Mission Related Studies**

  "How are total configurations of people and equipment constructed for maximum tactical and strategic effectiveness?" This concerns the optimum combination of individual and team performance within the total operational system. This combination applies not only to major ground, sea, air and subsurface systems, but to the command and control of these systems as well.

The principal products from each phase of system acquisition should be a meaningful way to represent the scope of human factors in a military system development. These phase-products should vary in specificity from the very conceptual requirement level to the very detailed design level, just as is the case with products of engineering logistics, etc., during each phase. After a great deal of analysis and synthesis (discussed primarily in Chapters 2, 3, and 4), a set of human factors products has been defined. For the purposes of this report, the principal human factors products from each major phase of the system acquisition process are identified below.

MAJOR PHASE OF SYSTEM ACQUISITION	PRINCIPAL HF R&D PRODUCT
Mission Analysis Phase	– Development of the Role of Man as a part of a Mission Element Needs Statement (MENS)
Concept Development Phase	– Allocation of System Functions to Man as a part of the Decision Coordinating Paper (DCP)
Demonstration/Validation Phase	– Task Analysis and Determination of Human Engineering Requirements
Full-Scale Development Phase	– Design of the Optimal Man-Machine Interfaces

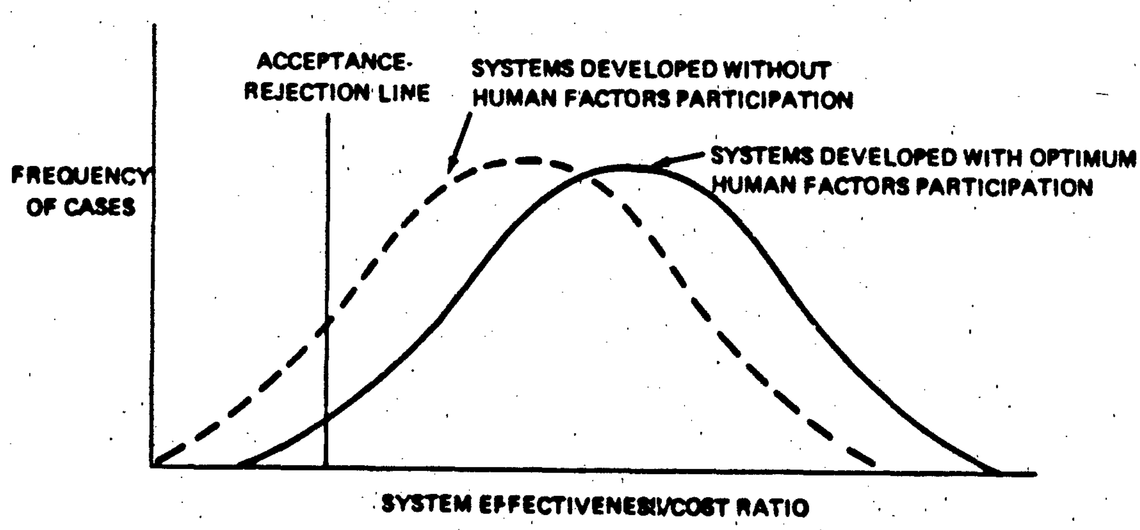
A more definitive explanation of these products is offered in Appendix A. Additionally, the payoff or value that can be realized at each phase of system acquisition will be explored. For the moment, the purpose of identifying the principal products is to bound the scope of what we mean by human factors, and to suggest that each product will require some costs and must yield some benefits.

The Integration of Human Factors and Military System Development

The problem of proper integration of the human factors contribution into the development of military systems can be dramatized by asking the question, "What result would occur if the development process involved zero human factors participation?" A completely non-controversial answer to that question can be cast in a statistical framework. That is, you would get a distribution of outcomes. In fact, the best hypothesis would be that the distribution would be symmetrical and near-Gaussian because of the multitude of influences at work. Such a hypothetical distribution is presented in Exhibit 1-3 as the dashed-line curve. The solid-line curve represents the characteristics of the distribution shift (again hypothetical) when the human factors contribution is introduced early and continuously throughout the development process. (One should probably interpolate a family of distributions to represent various degrees of human factors participation at less than optimum levels.)

Exhibit 1-3

Hypothetical Distribution of System Development Outcomes With and Without Optimum Human Factors Participation



Careful examination of the distributional model presented in Exhibit 1-3 can help in the process of understanding various aspects of the resistance to human factors participation on the part of some managers of military system development efforts. It is clear from the diagram, for example, that <u>some</u> systems could achieve acceptance (in the sense of going into full-scale production) with little or no formal human factors participation. Thus, if the program manager were "lucky," he could avoid the cost of that contribution. In the same vein, there are <u>some</u> systems below the rejection line that did have optimum human factors participation--substantiating the point that such participation does not guarantee success.

However, the diagram also reveals that a rational strategy would be one which always incorporated human factors participation. The program manager who does otherwise is simply playing against the odds if the postulated relationships in Exhibit 1-3 are valid.

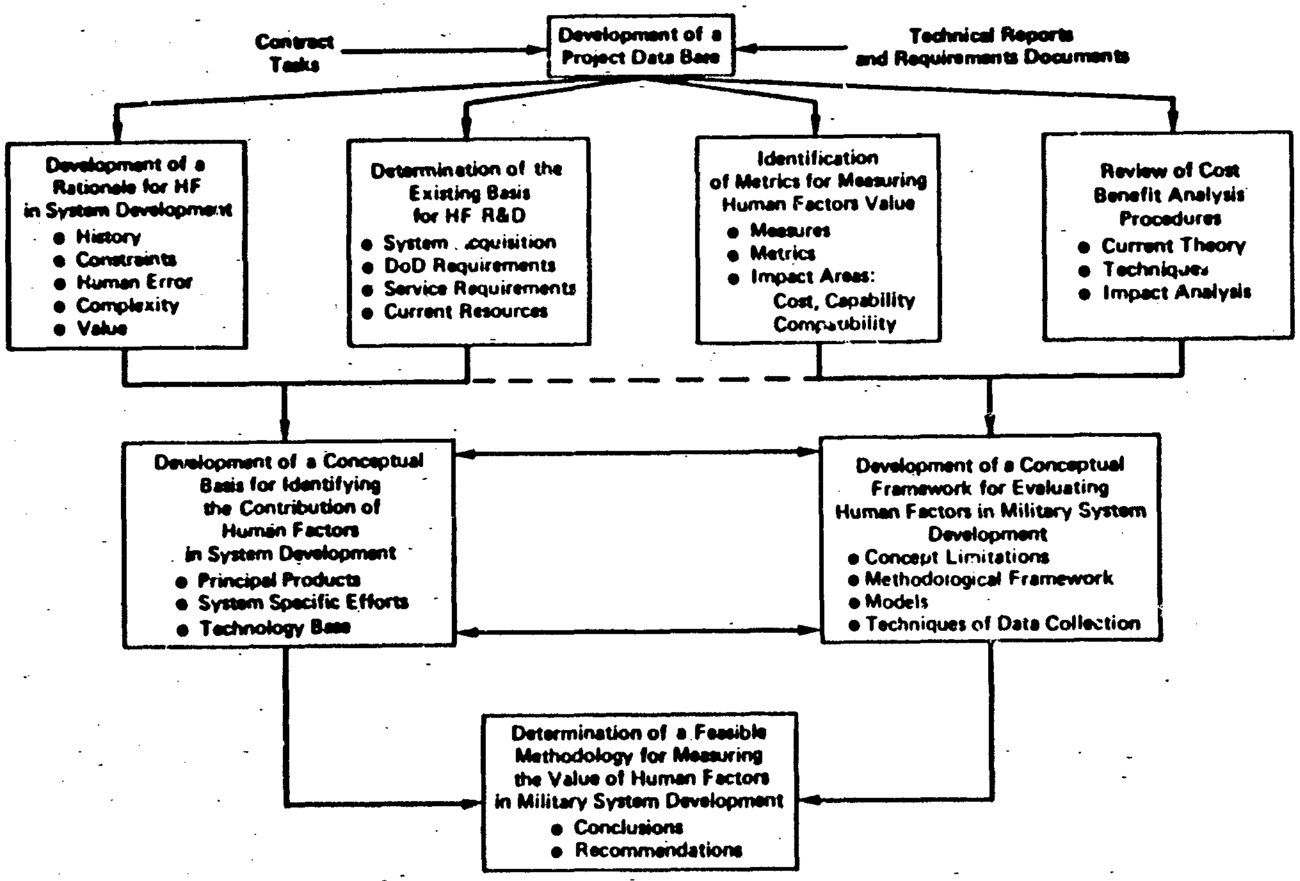
Overview of the Project

The present project constitutes very much of a team effort. At the top, the planning, analysis, and review process was carefully coordinated among representatives of the three services, the COTR, and the contractor. The project was scheduled into three phases which were intentionally set up to be partially iterative, but with a definite pattern of progression. At the completion of each phase, a comprehensive review was made and highly specific feedback and orientation was provided by the review panel to the contractor. Between formal review sessions, guidance was provided by the COTR and other advisors from the HFE-TAG.

A useful overview of the component structure of the project is provided by Exhibit 1-4. To a degree, each box corresponds to a major effort of the project, but does not correspond to a chapter in the report. Those boxes on the left side of the chart represent the efforts to identify the contribution of human factors in system development. The results of these efforts are reported in Chapters 2, 3, and 4. Those boxes on the right side of the chart represent the efforts to identify a framework for evaluating human factors contributions. The results of these efforts are reported in Chapters 5 and 6. The final box corresponds to the final chapter in the report.

The main message that should be drawn from Exhibit 1-4 is the intricacy of the relationship between the efforts and the essential symmetry of that relationship. These attributes are, at the same time, both the cause and the result of the teamwork within the working level of the project. Human factors content, human factors research methods, military system development procedures, program management practices, and the philosophy

Exhibit 1-4
Relationship of the Major Efforts of the Study



and methodology of cost-benefit analysis and related approaches all had to be brought into the work effort and made to be mutually constructive. The diversity is represented in the diagram. The constructive aspect is symbolized by the symmetry of the links.

Specific examples of particular applications of human factors to particular systems and instances of various attempts to evaluate the impact of such applications are scattered throughout the narrative, but examples of the linkage between human factors products and impact analysis criteria as mediated by system metrics are also contained in an appendix (Appendix C).

Human Factors in Military Systems

In Chapter 2, the question of the contribution of human factors to the development of military systems is considered in historical context. The evaluation of the speciality is shown to have been based on tangible results. It is also revealed that while the content of the contribution was often based on quite rigorous scientific procedures, the evaluation of the contribution, in the sense of establishing human factors as an essential ingredient in military system development, was either neglected or handled by anecdotal evidence.

The anecdotal evidence is persuasive as far as it goes. Moreover, the philosophical base upon which both human factors specialists and system engineers and the other disciplines were working tended to be an increasingly integrated one during the period from the late 1940s to the late 1960s.

During this same period, the formalization of the role of human factors in military system development was accomplished. The first generation of official directives has since been revised many times, but the most recent versions contain clear reiterations of the recognition of the requirement for contributions from human factors sources that was first officially articulated in the 1950s. A summary of the formal basis for human factors participation in military system development is presented in the first section of Chapter 3. The formal instigations are seen to be linked to the structured chronology of the system development process. This very structure sets the stage for the further conceptualization of the mode of contribution that is the subject of the balance of Chapter 3. In these sections, the key message is that the contribution of human factors can be characterized as specific products, each

of which is tied to a stage in military system development. Further, a simple model has been prepared which identifies specific human factors efforts that make up the products of each system development phase. Finally, in Chapter 4, there is a brief treatment of how human factors R&D from the technology base can also contribute to the principal human factors products of each system development phase.

This conceptualization of human factors contributions reinstates the condition of the tangible consequence that characterized the early development of the speciality. As such, the stage is further set for the possibility of a rigorous evaluation approach, one that represents a clear advance over the retrospective and anecdotal approaches of the past.

The Measurement of Human Factors Contributions

The concern for a feasible method to measure and evaluate the human factors contribution to military system development did not suddenly arise as part of an attempt to rescue human factors from oblivion. The concern is primarily a manifestation of two parallel trends in the much larger arena of public administration. These trends can be briefly characterized as a growing sense of a need for stricter accountability in the expenditure of governmental resources and the evolution of rationalistic procedures for providing such accountability.

Military systems development is unquestionably an area of expenditure of government resources. The major public policy issues that are associated with these processes have to do with allocation-of-resources decisions. Should public funds be invested in system X or system Y or system Z? Such allocation decisions presumably should be guided by analytic results in the form of estimations of relative returns on investment (ROI).

Below the level of choice between X, Y, and Z are a series of subordinate choices. Having decided on X as the best potential system, what should be the proportional investment in technology A, B, and C? When either A, B, or C might make a crucial contribution to the effectiveness of system X, what mix will yield the best potential payoff?

At the most basic level, these questions are technical questions for the political economist. And, indeed, it has been from that source and from disciplines such as Operations Research and others that have an intellectual affiliation with political economics that the evolution of rationalistic procedures has come. A central contribution of this evolutionary effort has been the formal methodologies under the rubric of cost-benefit analysis. Consequently, the cost-benefit approach is used as a starting point for the specific tailoring of a methodology to meet the objectives of the present project.

As it turns out, the strict monetary criteria required in formal cost-benefit analysis make it awkward to apply in its pure form to our central problem. However, the basic logic of the methodology and its inherent emphasis on quantification do provide a productive orientation. This orientation is reflected in Chapters 5 and 6, which cover measurement metrics and methodology, respectively.

The point is that the work reported here is well within a conceptual movement that might, by this time, be called a tradition.

Of specific precedents, however, there have been precious few. There are so few, in fact, that to achieve some perspective on the present enterprise, it is necessary to examine another parallel literature: that of evaluation in education and training.

The specific application of approaches resembling those of cost-benefit analysis had its own broad history in the general movement toward treating education in a more scientific way (see, e.g., Campbell and Stanley, 1963). The lift-off point came, however, in the mid-to-late 1960s with the work of Suchman (1967) and, more particularly, Stufflebeam (1968). The past decade has witnessed the production of many hundreds of articles and reports, most of which were focused on the actual evaluation of some particular educational or training program or a particular training technology, and a few of which were focused on methodological advances, as such, or what might be called the "management of evaluation." An up-to-date example of the former is provided by the recent works of Orlansky and String (1977 and 1979) in their summary evaluations of the cost-effectiveness of flight simulators and computer-based instruction in military training. An example of the latter mode is provided by the work of Conley et al. (1979), in their review of six major government-sponsored training programs. Conley and his group, who work for the U.S. Office of Personnel Management (formerly the Civil Service Commission), were concerned with the very issues central to this effort: the need for evaluation, its feasibility, and the procedures for doing it in such a way that the outcome can be used to guide management decisions.

The key point is that, again, a substantial precedent exists for the general approach and, in these instances, the approach has been more or less successfully applied to an activity that is considered to be somewhat "soft" in the sense of its being exclusive of rigorous, quantitative measurement.

To return to the precious few direct antecedents, three examples can be cited. Each is of quite a different sort.

One such case is the work of Geer (1979). In a sense, it is the more remote precedent because the document as a whole is devoted to the problem of how to conduct human engineering analyses. Only a few pages (out of 220) are devoted to the evaluation of the human engineering contribution (pp. 24-25). The approach is built on a brief review of the TMI-2 incident and is affirmative and non-quantitative in character.

A second case is represented by the work of Price et al. (1979). In this case, evaluation is the central objective but the substance to be evaluated is the human factors effort in research rather than scientific system development. The approach taken, however, is to relate research (technology base) outputs to such achievements as cost avoidance in both military operations and training. In short, the benefit side of the cost-benefit ratio is stressed.

The third case is represented by a report compiled by the BDM Corporation (1980) that focuses on the human factors aspects of aircraft accidents. As such, the focus is much narrower than that of the present effort. However, it is closely akin from a methodological point of view, in that an attempt is made to evaluate the human factors contribution to aircraft accident prevention using an analysis of return on investment.

In a sense, then, we have come full circle. The present work, particularly as reflected by the contents of Chapters 5 and 6, represents an extension and focusing from three sources: the general source of allocation analysis in the public policy domain typified by the methodology of formal cost-benefit analysis; the parallel source exemplified by attempts to apply such rigorous methods to the evaluation of the elusive processes of education and training; and the very restricted source of specific attempts to evaluate human factors contributions through a linkage to some aspect of system effectiveness.

Chapter 5 reveals how the focus can be realized by means of quantitative measures that fit into the broader framework of system engineering. Chapter 6 describes how the measurement operations can be made and how they can be interpreted through the use of a conceptual model adapted from the basic structure of formal cost-benefit analysis.

The Concept of Impact Areas

A specific case is made in Chapter 6 that strict cost-benefit procedures are not appropriate for the evaluation of the contribution of human factors to military system development. The central reason is that strict cost-benefit models require a single ultimate criterion: monetary value. It turns out to be not only awkward but occasionally ludicrous to reduce the human factor aspect to a dollar measure.

Consequently, a compromise was sought. The goal became that of deriving a methodology that would be as close to strict cost-benefit methods as possible while covering the full scope of the human factors contribution. The existing derivation of cost-benefit methods that met that goal was policy/impact assessment.

The adoption of impact assessment as an exemplary procedure opened the door to another crucial adaptation. That is, it was discerned that the scope issue could best be met by adding a criterion factor called compatibility to the basic two, already labeled cost and capability.

Thus, a triad of criteria were adopted: cost, capability, and compatibility, and the members of the triad were designated as impact areas to directly connote that the proposed methodology was to be a version of policy/impact assessment.

The cost criterion is used in essentially the same way as it is in the cost-benefit methodology. It is expressed in dollars and pertains to the total life cycle costs of a system.

The capability criterion is very close to the benefit component of the cost-benefit methodology except that it pertains ultimately to system-mission performance and is not reduced to dollar value in the impact assessment version of the methodology.

The compatibility criterion is uniquely responsive to the substance of the human factors contribution. As a concept in its own right, it links logically to the consensual goal of human engineering, which is to achieve an optimum match among human, machine, and mission.

Because compatibility is something of an innovation in the lexicon of evaluation methodologies, it seems useful to give it a little extra attention. Specifically, we can break it down into its constituent parts: physical compatibility, physiological compatibility, and psychological compatibility. Physical compatibility refers to the human as a physical object having certain dimensions of size, weight, reach, etc. The design of workplaces such as the cockpit of an aircraft must provide for these physical attributes.

Physiological compatibility refers to the human as a functioning organism. Thus, metabolic processes such as respiration must be taken into account in design. Also, factors such as visual acuity under differing conditions of illumination are physiologically based and the designer errs if he or she specifies a display that cannot be read under operational conditions.

Psychological compatibility is the most complicated of the constituents. It breaks down further into behavioral and attitudinal components. Behaviors relate primarily to established habits such as the habit of turning a knob clockwise to increase some effect and counterclockwise to decrease. Design should be responsive to such habits.

The attitudinal component is manifest mainly in the phenomenon of user acceptance. Even under strict military discipline, users can reject involvement with a particular system. The reasons might not be entirely logical but can be nonetheless powerful. The prediction of such reactions or even their measurement after-the-fact goes well beyond conventional engineering considerations but lies well within the province of human engineering. It is in this domain that the need for special observational methods and measurement techniques becomes most obvious and where some of the particular justifications for adaptations or extensions of strict cost-benefit models derive. It is reconciling these variants with the mainstream of system engineering--bringing these aspects back into the family, so to speak--that constitutes one of the major contributions of the present project.

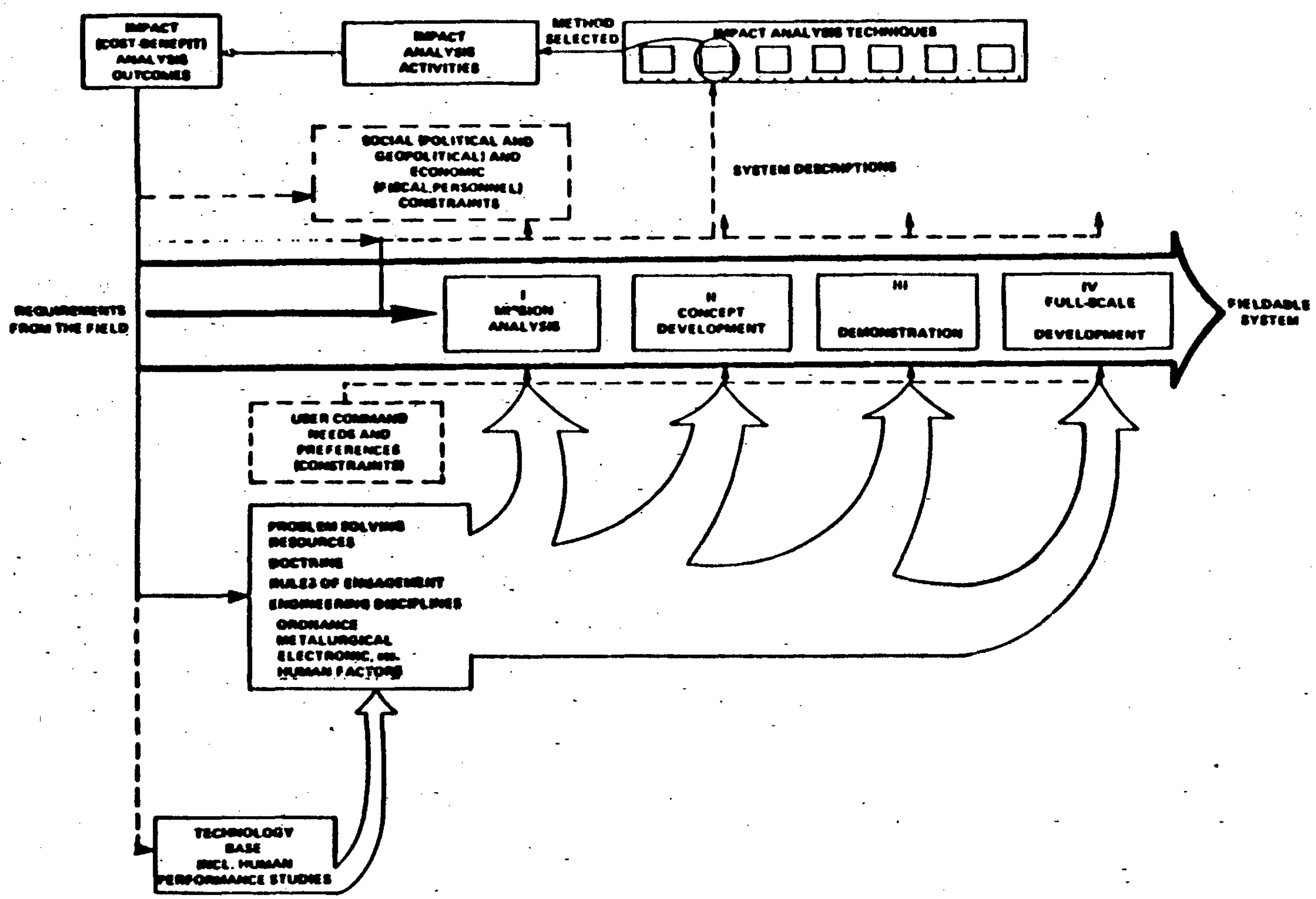
Summary and Synthesis

The total effort involved in the present project has already been revealed to be complex in the sense of being a composite of several different topics and orientations. This point is made even more dramatically in Exhibit 1-5, which represents an attempt to characterize the intended outcome in a composite summary format.

The central core of the representation is the system development process itself. It is shown as consisting of four phases denoted by Roman numerals.

Exhibit 1-5

Relationship of System Attributes to the Choice of Impact Analysis Techniques



The lower portion of the diagram stresses the role of the technology as provider of the problem-solving resources. In particular, the engineering disciplines are specified, including human factors.

In a similar way, the role of technology base activities is shown: to support the evolution of the problem-solving resources.

The upper part of the diagram emphasizes the feedback mechanism introduced at the beginning of this chapter. The function of the impact analysis, in the first instance, is to provide techniques for data gathering. The convention used is intended to show that different techniques can be used under different circumstances and that some choice must be made.

The outcome of impact assessment is then shown to feed back primarily to the problem-solving resources box because that box is also the locus of the management decisions in military system development. That box, indeed, is the ultimate target of the project reported here.

References

Campbell, D.T., & Stanley, J.C. Experimental and quasi-experimental design for research in teaching. In N.L. Gage (Ed.), *Handbook of research on teaching*. Chicago: Rand McNally, 1963.

Conley, M., et al. (Workforce Effectiveness and Development Group). Report of the Training Evaluation Demonstration Project: Issues and recommendations. Washington, D.C.: U.S. Office of Personnel Management, March 1979.

Erikson, R., Miles, J., & Secrist, G. Technology Coordination Paper: Training and personnel technology. Department of Defense, August 1978.

Fiorello, M., Jukes, A., Kidd, J., O'Connor, D., Price, H., Swezey, R., & White, T. DOD people-related RDT&E: Reference document. WN ML 909-1. Logistics Management Institute, Washington, D.C., March 1979.

Geer, C.W. Human engineering procedures guide. F33615-79-C-0520. Aerospace Medical Research Laboratory, WPAFB, Ohio. Boeing Aerospace Company, Seattle, Washington, December 1979.

Orlansky, J., & String, J. Cost-effectiveness of flight simulators for military training. Vol. I: Use and effectiveness of flight simulators. IDA Paper P-1275. Institute for Defense Analysis. Office of the Director of Defense Research and Engineering, August 1977.

Orlansky, J., & String, J. Cost-effectiveness of computer-based instruction in military training. IDA Paper P-1375. Institute for Defense Analysis. Office of the Secretary of Defense for Research and Engineering, April 1978.

Price, H.E., & Sands, F.F. (Eds.). The utilization of people-related RDT&E. Navy Personnel Research and Development Center, San Diego, CA, April 1979.

Stufflebeam, D.L. Toward a science of educational evaluation. *Educational Technology*, July 1968.

Suchman, E.A. *Evaluative research*. New York: Russell Sage Foundation, 1967.

U.S. Air Force School of Aerospace Medicine. Definition of investigation areas for human factors aspects of aircraft accidents. F33615-78-C-0608. BDM Corporation, February 1980.

CHAPTER 2

A RATIONALE FOR THE VALUE OF HUMAN FACTORS IN SYSTEM DEVELOPMENT

The substance of this chapter includes a brief review of the historical evolution of human factors in military system development and a compilation of the established arguments in favor of the utilization of the human factors resource by program managers.

One conclusion is that those involved in one or another aspect of military system development--particularly during the past ten years or so--have allowed what should be a strong collaboration-type relationship to take on some of the features of an adversary relationship. The present project constitutes an attempt at "rapprochement" by expanding upon the established rationales for the use of human factors resources through the elucidation of methods permitting a more explicitly objective assessment of their value.

For those readers who are already convinced of the value of human factors in military system development, this chapter can serve only as a quick refresher course with some special emphasis on the constraints involved in achieving timely participation. For the more skeptical, the chapter should reveal that the effort to promote human factors in military system development does indeed have an established rationale that is substantial, even though its powers of persuasion have not been overwhelming in recent times.

Historical Background of Military Human Factors

The history of human factors in the military has been reviewed many times (see Meister & Rabideau, 1965; Christensen, 1976; and Chaikin, 1978) and will not be dwelt upon here. Essentially, there is a consensus that the major requirement for human factors contributions to system design occurred during World War II and grew out of earlier work in aeromedical research, industrial psychology, and industrial engineering. As expressed by Meister and Rabideau (1965):

> With World War II a new factor entered which had tremendous consequences for human factors. This was a period of increases in technological complexity, involving such new systems as radar and sonar and highly complicated fighter and bomber aircraft, designed to be used in new environments and under highly demanding conditions. These conditions, under which the operator could not function as readily as he had before, complicated medical, physiological, and psychological requirements for design.

In the lore of human factors, the oral tradition asserts that in the early stages of mobilization, the Army in particular had a surplus of psychologists. For lack of a better assignment, two or three of these individuals were given the "detail" of reviewing a rash of P-47 accidents. Several of these aircraft had crashed when the flaps had been lowered on takeoff when the wheels were still down. The problem turned out to be a confusion of two controls (flaps and wheel retraction) by pilots who had been trained on an aircraft in which the flap and wheel controls were reversed from their location in the P-47 cockpit. The ability of the psychologists to "solve" the problem convinced some key officials that it would be a good idea for a psychologist to look at all new systems to ensure that no "traps" were included in the design for the unwary operator.

Later, when the major electronic systems were being brought into operation, human factors participation had become more or less routine. The so-called "team approach" that included the human factors scientist had become a basic rule in the minds of such system pioneers as Churchman, Ackoff, Arnoff, Roy, and Flood.

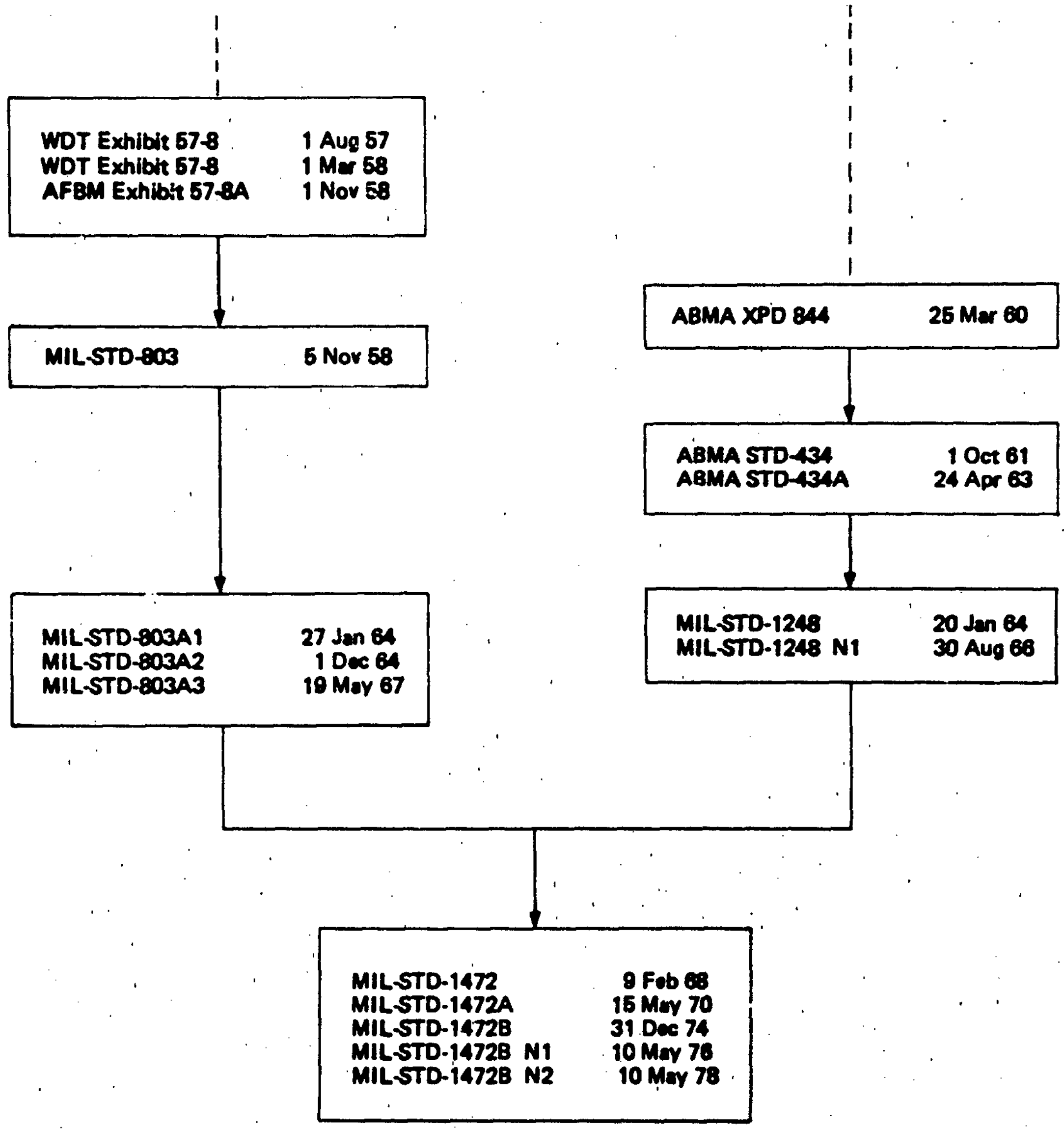
It is notable that at this still-early stage in the history of the speciality one generic problem was characterized as system complexity. We were already seeing systems with large numbers of interactive components where the functional relationship between such components was not self-evident to ordinary operators or maintenance technicians and where many of the components were not "familiar" to such personnel. The current situation with respect to military systems is a direct extension and major expansion of the trend that started at that time. Forty years later we are still talking about the complexity of military systems and their demands on the capabilities and limitations of people.

No more history need be provided here except to make two further points. The first is that during the years from World War II until today, an enormous amount of human factors data has been developed, much of which has been incorporated into handbooks, guidelines, specifications, standards, directives, etc. An excellent overview of this historical development is provided by Chaikin (1978), who also charts the development of MIL-STD-1472, Human Engineering Design Criteria for Military Systems, Equipment, and Facilities (see Exhibit 2-1).* The second point

*Along these lines, it might be useful to consider the possibility that the human factors vocation is to some extent a victim of its own successes. In a sense, the early findings (and admonitions) of human factors specialists have become a standard engineering practice. If the technology had remained the same or had evolved only very slowly, the whole story would have concluded with a condition in which the human factors specialist has "worked himself out of a job."

Exhibit 2-1

Development of MIL-STD-1472



is that despite this enormous accumulation of data and the directives, standards, specifications, etc. for enforcing the application of human factors in military systems, that portion of human errors which generally can be attributed to deficiencies in equipment system design is still a severe problem in the Army, Navy, and Air Force today.

The issue of complexity and the problem of human error and its relationship to system effectiveness will be discussed in the next two sections. A separate section on optimal manned systems and the compatibility factor will follow. The final three sections will address the questions of opportunity, using what we know, and the affordability of human factors.

Military System Complexity and Human Factors

The notion that the complexity of military systems was the driving force behind human factors (or human engineering) literally coming to life in World War II is still with us. For 30 or 40 years someone has been saying that the current or abcut-to-be-introduced systems are complex and require special consideration of human elements. During this same time period, however, no one seems to have defined complexity, nor to have quantified it. What is apparent is that systems are at least different today from what they were 30 years ago, and that most systems in the military are being rapidly replaced by newer, high-technology versions. In any event, the complexity theme is appropriate to establish the value of human factors in military systems development.

Complexity (or some synonym) has been mentioned at all levels of the Department of Defense recently. For example, Dr. Harold Brown, the Secretary of Defense, in his annual report to the Congress, FY 79, stated the following (pg. 9):

> . . . Modernization, in some cases, has brought with it shorter mean-times to failure, longer repair times, and increased training requirements, as well as greater sophistication and capability of equipment. Inflation, increased pay, and the need to modernize our forces have meant curtailed funds for operation and maintenance.
>
> . . . Accordingly, we must keep up our training not only because U.S. forces may be sent into action with very little advance warning, but also because we rely increasingly on the sophistication of our equipment to compensate for potential superiority in enemy numbers. It is equally essential that our war reserve stocks be maintained, mostly for our own needs, but to some degree for Asian allies as well. At the same time, we must raise the percentage of our equipment that is combat-ready because, owing to unit costs, we have less of it to bring to bear in an emergency.

> To put the matter bluntly, unless we are prepared to maintain these components of readiness, collective security and deterrence will be seriously undermined . . . .

Dr. Brown refers to the sophistication of modern equipment rather than complexity. He also talks about the need to raise the percentage of equipment that is combat-ready; and while he does not say so in the excerpt, all military system readiness is measured in terms of both equipment readiness and personnel readiness. Obviously, a piece of equipment that *can* perform its mission, but that *will* not because the operator cannot operate or maintain it, is not combat-ready.

General William E. DuPuy, in a speech in 1977 describing the Army training system, also deals with the complexity issue. General DuPuy talks about problems converging on the Army and makes the following statements:

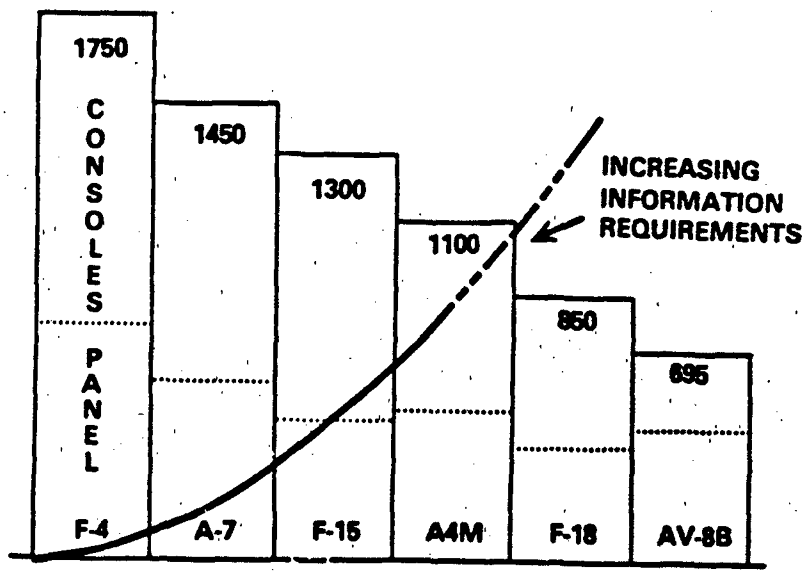
> The first thing that is converging is all that new equipment. The rate of introduction of new equipment will increase exponentially. The first thing that goes like that is the amount of equipment that is going to arrive in the Army between 1978 and 1985. And the Army has to digest it. Traditionally armies have a hard time digesting new things. We all do, especially organizations like armies. Anyway, that's the first area of convergency. You are going to be innudated with new tanks, new MICV's [Mechanized Infantry Combat Vehicles], new TACFIRE's [Tactical Fire Direction Systems], Battery Computer Systems, Patriots, ROLANDS, a whole new set of communications equipment, a whole new set of electronic warfare equipment, and on and on . . .
>
> Complexity is another problem converging on the Army. Every single new system being fielded is more complex than the one it replaces. This complexity is getting to be more of a problem than just operating and maintaining it. But the complexity of this new set of equipment raises, if you will, integrated complexity.

The issues of introduction of new equipment and complexity can be dramatized by examining Exhibits 2-2 and 2-3. These exhibits are from recent briefings on the human factors program at the Naval Air Development Center. Exhibit 2-2 indicates the dual problem of increasing information requirements for aircraft operators and the decreasing available cockpit space for providing displays or controls. As may be seen, the last weapon system on that chart, the AV-8 (Harrier) V/STOL aircraft, has approximately one-third of the cockpit space that the F-4 aircraft has.

Exhibit 2-2

Cockpit Space and Information Requirements for Several Navy Aircraft Weapon Systems*

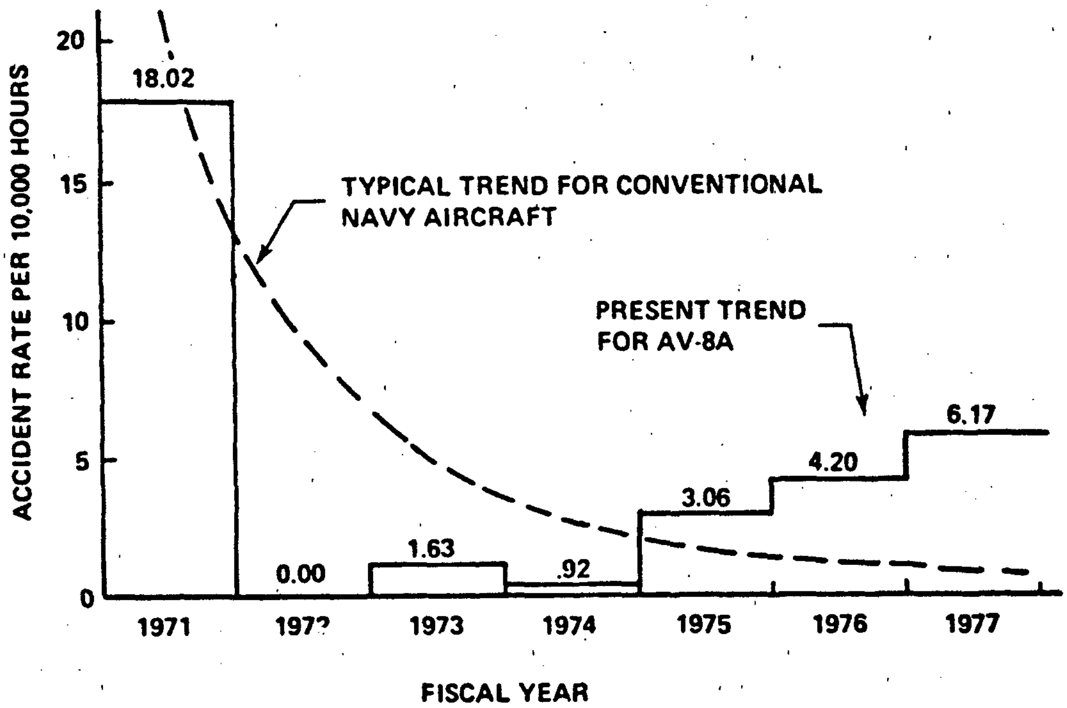
Available Cockpit Space (in^2)



*This chart is from a brief provided by the Human Factors Engineering Division of the Naval Air Development Center, Warminster, Pennsylvania.

Exhibit 2-3

Trend of Accident Rates for Typical Navy Aircraft and the AV-8A Harrier*



*This chart is from a brief provided by the Human Factors Engineering Division of the Naval Air Development Center, Warminster, Pennsylvania.

Exhibit 2-3 shows a disconcerting trend, namely, that the current V/STOL accident rate is increasing. This is contrary to the experience typically encountered when new aircraft are introduced. Furthermore, "pilot factor" as a contributing cause seems alarmingly high. With respect to this last point, the data shown in Exhibit 2-3 represent 21 accidents, 16 of which occurred in the V/STOL flight regime (i.e., conversion flight, landing, or takeoff). Of these 16, 11 had pilot factor as a contributing cause. It should also be added that the Naval Air Development Center has since initiated a program to provide human factors support early in the design of V/STOL aircraft.

Human Error, Human Factors, and System Effectiveness

The operators and maintainers of military systems do make errors and many, if not most, of these errors can be traced to faulty design. In a classical study by Shapero et al. (1960), a survey of nine Air Force missile systems showed that human error contributed from 20-53% of system unreliability. These percentages referred only to human errors during field exercises with these systems, i.e., errors during the launch or relaunch activities. The study did not attempt to go back into the life history of each system and find human errors in the design and fabrication of each. Swain (1964) comments on the Shapero report in the following way:

> Human errors have a greater effect on system reliability than many people realize . . . . In most cases, it is more efficient to redesign procedures and equipment which can minimize or even eliminate certain types of human errors. Engineers can be taught valuable design principles to minimize human error, but engineers cannot take the place of a human factors specialist.

Swain also emphasizes the human engineering problem based on a Sandia investigation of human error which analyzed a large number of production defects at the plant of an AEC prime contractor. It was found that 82% of the defects could be directly attributed to human error.

Meister and Rabideau (1965) also discuss the problem of human error and develop the link between human error and human factors and system effectiveness. They quote some human error percentages (page 15) from other sources which estimate:

> . . . that 40% of the problems uncovered in missile testing derive from the human element. 63.6% of the (shipboard) collisions, flooding and grounding could be blamed on human error. Reports produced by the United States Air Force indicate that human error was responsible for 234 of 313 aircraft accidents during 1971.

More recently, Coburn (1973), in a paragraph describing the benefits from systematic human engineering, again states the problem of human error and its relationship to human factors (human engineering):

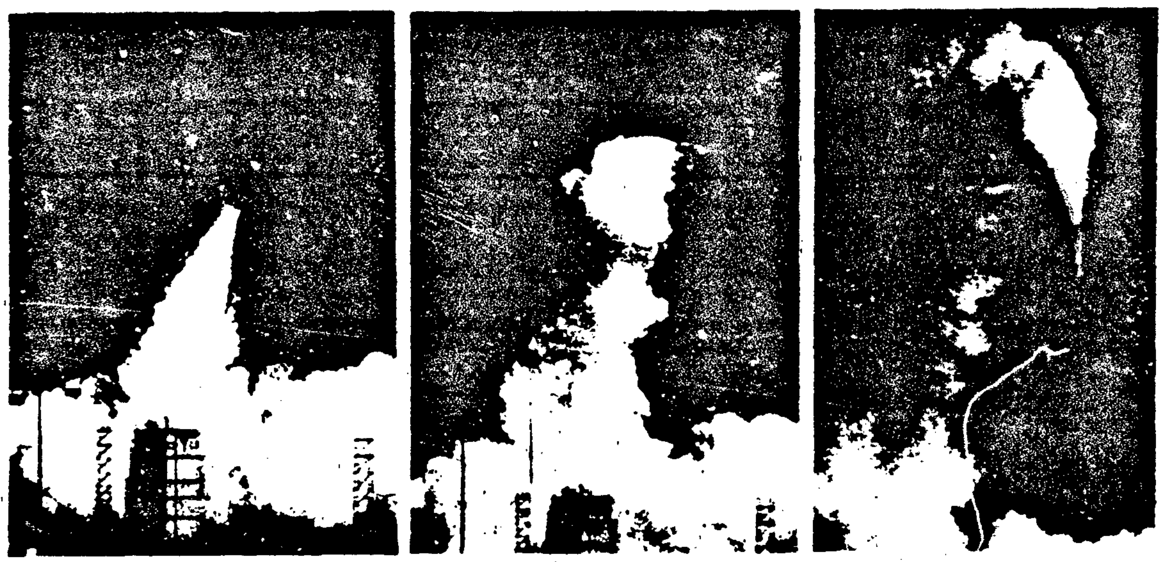
> The payoff in conducting a systematic human engineering program is realized in improved system performance, reduced training cost, improved manpower utilization, fewer errors and accidents, reduced maintenance costs, higher probability of mission success, and improved user acceptance. Without applying a systematic human engineering program, attainment of an effective ship system is fortuitous and improbable.
>
> Failure to apply systematic human engineering can be costly--research indicates that typically up to 40% of all ship system malfunctions are attributable to human error.* Even increasing automation of ship systems does not eliminate the application of human engineering programs, since man is still involved as a user and maintainer.
>
> To maximize the payoffs previously cited, human engineering must be applied throughout the ship system life cycle. It starts with inputs to planning documents and continues throughout concept formulation, contract definition, engineering development and production, test and evaluation, and finally fleet operations.
>
> ---
>
> *Pickrel, E.W., & McDonald, T.A. Quantification of human performance in large complex systems. *Human Factors*, 1964, *6*, 647-662.

Finally, the effect of human error was dramatically illustrated recently in *Time* magazine (January 8, 1979) by the photographs shown in Exhibit 2-4 and the simple description noting human error, which is included here verbatim.

Exhibit 2-4

A Trident Missile Test at Cape Canaveral

Photographs from *TIME*, January 8, 1979 by Mark/Norman Summey



A MISSILE'S UPS AND DOWNS

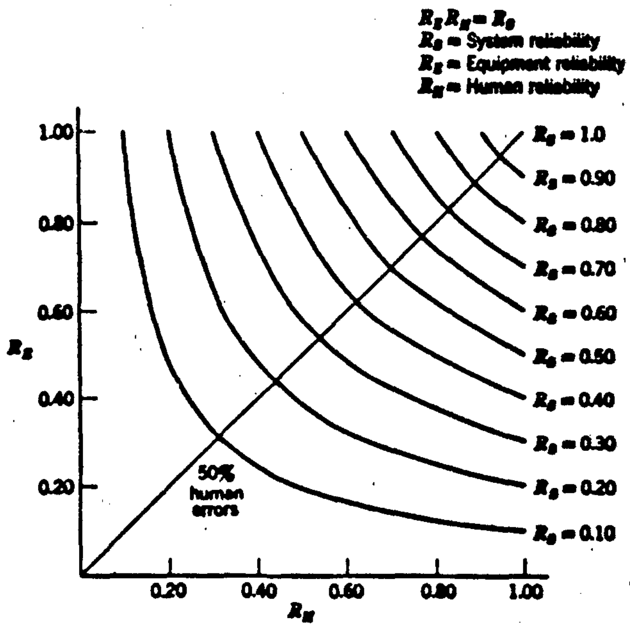
It was one of the most dramatic flights in missile history, all recorded in these exclusive photographs for TIME. The Trident had hardly left its launching pad at Cape Canaveral when it started to wobble wildly. About 500 ft. in the air, it suddenly made a boomerang turn; then exploded and smashed to earth 125 yds. from its takeoff site. The fallen missile burned fiercely for 10 min., sending a column of white smoke soaring skyward, but no one was injured. It was the third failure out of 17 Tridents tested to date, and the cause was human error. Someone included an extra step in the check list, which led to the guidance system's shutting down a half-second before ignition. The missile, which is designed for submarine launching, was out of control from the moment of takeoff. The Navy's calm term for the Trident's destruction: "No test."

The point of the above discussion on human error is that the real value of human factors is to reduce actual or potential human error or increase human reliability. It is not just human reliability but the consequences of human reliability on system reliability that are important. The relative impact of human error on system reliability has been shown graphically by Meister and Rabideau (1965). They discuss this graph (Exhibit 2-5) in their own words as follows:

> . . . shows the relationship between human reliability R_H and equipment reliability R_E and their contribution to overall system reliability R_S. Thus, an R_E of .85 coupled with an R_H of .90 produces an R_S of approximately .78. Lower the human reliability to .30 with the same equipment reliability of .85, and system reliability now becomes .25. It is apparent, therefore, that anything which decreases R_H must be a primary concern of the human engineer. It is assumed that much of this error results from inadequacies in system design which create favorable conditions for error occurrence.
>
> Error potentiality resulting from inadequate design can only be eliminated by systematic and continuing evaluation through the development of that design. If the human factors aspects of system performance are not routinely evaluated, it is very likely that they will be overlooked, with the result that the particular system function involved will be developed inefficiently.

Exhibit 2-5

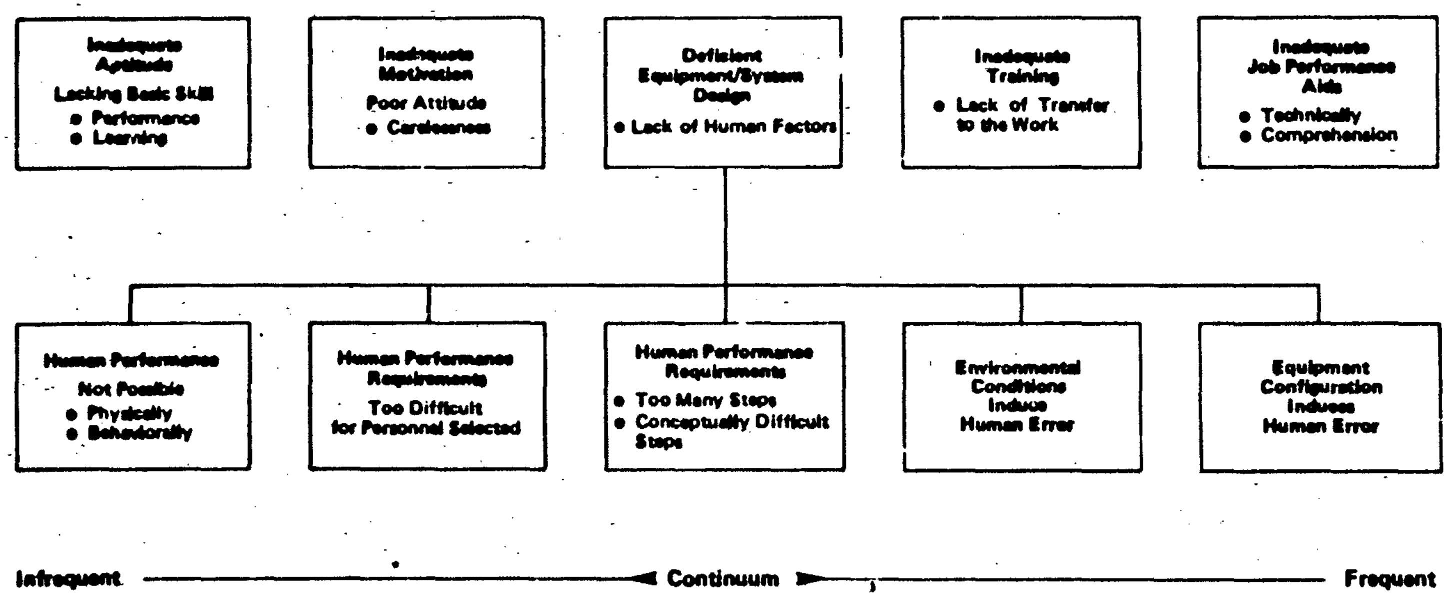
Effect of Human and Equipment Reliability
on System Reliability, $R_E \times R_H = R_S$



All human error is not, of course, a function of poor human factors. In a paper included in the Minutes of the 12th Training and Personnel Technology Conference on "Human Factors in Weapon System Test and Evaluation" (Taylor, 1978), John Miles of the U.S. Army Human Engineering Laboratory developed a chart of various sources for attribution of human error. This chart has been modified and expanded and is included as Exhibit 2-6. As can be seen, there are five basic sources which can account for human error in military systems; and there are five types of deficiencies in equipment system design which human factors application should resolve or minimize. It is also worthy of note that the five typical sources of human error (the top of the chart) may also be turned around and viewed as the five principal techniques for achieving performance competency in

Exhibit 2-6

Typical Sources for Attribution of Human Error



personnel. These five techniques for performance achievement are discussed by Price (1979). He points out that human engineering (human factors) is seldom used early in system design to obtain performance competency. Traditionally, performance competency is obtained through selection and training; and, more recently, emphasis is being placed on improved job performance aids. Still more recently, motivation is receiving more emphasis. All of these approaches have their place and their problems. In brief:

- Training is becoming extremely expensive and is "under the gun" by DOD and Congress.
- Job performance aids are showing great promise, but have yet to prove their cost effectiveness on a long-term basis.
- The ability to select for aptitude is not a course that is readily available in the military any more, as is pointed out by Rook (1965):

  > The more rational course is to use the capabilities of people as we find them and to create situations in which the job at hand can be done by the people we get, rather than only by the people we wish we had.

- Finally, motivation as a way of reducing human error is important; and it is also important for the long-term effects that can be achieved through job design (see Price, 1979) which affect the total personnel system. However, from a performance point of view, Rook has pointed out that "motivational schemes have nearly always produced transient results in which maximum performance increases are usually about 30% or less." Rook also discusses that a much greater potential for reducing error is by modifying the performance situation (human factors). He states that:

The amount which errors can be reduced and quality improved by changing environmental conditions is virtually unlimited--if your money and time are also unlimited. By pinpointing error-likely situations and designing around them, almost any error can be reduced to a tolerable level . . . . The most significant point to be made about situational changes is that they are relatively permanent.

Optimal Manned Systems--
The Compatibility Factor

In the first chapter of this report we identified cost, capability, and compatibility as the three impact areas that should be used to assess the value of human factors in military system development. The preceding section discussed human error and system effectiveness wherein system effectiveness relates to the impact areas of both capability and cost. This section will acquaint the reader with the third impact area, compatibility, via a discussion of optimal manned systems.

> . . . where those systems which man himself plans, designs, and constructs are concerned, I submit to you that there is no such thing as an 'unmanned system.' It must be appreciated as axiomatic that all such systems have a man or men somewhere in the loop between planning, attempting, and replanning. Whether the question is one of foolproof assembly, skillful maintenance, unerring operation, or parrying counteraction, man's performance in relation to the equipment which is involved will decisively affect the accomplishment of the 'system.'
>
> The corollary to this axiom is that the impact of man's characteristics must be taken into account in the design of the equipment if the system is to possess maximum probability of achieving the goal for which it was designed in the first place. (Flickinger and Hetherington, 1957)

The preceding quotation is an excerpt from a paper presented by Brigadier General Don D. Flickinger at a symposium on human factors in system engineering. The point is just as valid today as it was when made over 20 years ago. Moreover, there is such a thing as an "optimal manned system" in which the demands of the operational system exploit man's unique capabilities and compensate for his limitations. In other words, an optimal manned system is one in which man is most compatible with his designed

role, functions, tasks, and system interfaces. This "compatibility factor" and the notion of an optimal manned system may be best understood by considering some of man's characteristics in a system setting. Generalized statements about human capabilities and limitations are of course subject to the interpretation of specific systems and environments. However, the generalities offered below serve to establish an awareness of the compatibility factor.

Unique Human Capabilities

In complex systems, man makes the most significant contribution in situations where all of the performance alternatives cannot be specified in advance and thus pre-programmed. Humans will adapt to any changes in the system input and environment. This characteristic is mandatory where the relations between input and output may require restructuring in the course of mission accomplishment and where all operations cannot be reduced to logical, preset procedures.

Man makes possible a more diversified system mission. He can translate uncertainty into probability and deal with low probability/high value exigencies; and he can develop a "behavioral strategy" when no optimum strategy can be specified. His ability to perform a variety of functions and to utilize alternatives means more is accomplished, including multiple mission performance, recallable mission attempts, less vulnerable mission accomplishment, and vehicles returned for re-use.

Man has the ability to make and report unique observations and experiences, including observations on his own performance, observations on system performance, observations of a scientific nature, and incidental intelligence.

Man will enhance system reliability. Significant human capabilities which may not be easily duplicated by a machine in so small and reliable a package include:

- Selection among alternative ways of achieving a mission;
- Integrating a large amount of information gathered from experience and bringing it to bear in a novel situation;
- Sensitivity to a wide range of stimulus patterns;
- Capability to detect signals through noise;
- Capability to act as an intermittent servo in the performance of a number of different systems or equipment.

Human Limitations

Man comes in only one physical model and can only be integrated into the system concept as a physical whole, with certain general characteristics of size, weight, shape, strength, etc.

Man has certain performance limitations such as sensitivity, reaction time, number of information channels, rate of operation, environmental stress tolerance, etc.

There is a definite price to pay for maintaining reliable performance potencial in man, in terms of training, maintenance of proficiency, manuals and other job guides, and human factors design.

Man has life support needs. His performance deteriorates rapidly when these physiological needs, such as nourishment, environmental protection, sleep, comfort, and general health maintenance are not satisfied.

Man has psychological needs. His performance usually deteriorates over prolonged periods of high stress or non-activity, and can change significantly as a result of such psychological variables as motivation, frustration, conflict, fear, etc.

Compatibility and User Acceptance

A review of the capabilities and limitations just stated will reveal that compatibility is physical, physiological, behavioral, and attitudinal. The physical and physiological compatibility is basically obvious and non-controversial. Man cannot be expected to perform if he cannot fit into a crew compartment or he cannot reach the controls or he cannot breathe. Behavioral data and man's sensory, perceptual, cognitive, and motor capabilities have to some extent been used during system development, at least with respect to human engineering of man-machine interfaces. However, man's attitudinal system (i.e., acceptance) has not been systematically included in man-machine systems design. This is a serious error as a highly motivated man can compensate to a considerable extent for poorly designed equipment or he can get the best out of equipment he likes. It is true that if a system is designed so that it is easy for the man to grasp and manipulate the controls, and if the displays are easy for him to perceive and understand, then, certainly, the system will be more acceptable and utilization will be enhanced. However, these traditional human engineering efforts are not sufficient in themselves to account for total acceptance. A man dissatisfied by a particular system design due to status, economic, or survival fears, or simply a desire to operate the system manually because he enjoys it, may not properly use equipment which has been designed to meet all other criteria. He will reject, underuse, or misuse the system, consciously or unconsciously. Consequently, system effectiveness may suffer regardless of the inherent reliability of the equipment per se.

The user acceptance issue may be even more prominent in advanced systems concepts incorporating extensive automation. For example, one approach to achieving the long-standing objective of highly reliable aircraft landing operation under severely degraded visibility conditions lies in the increased application of automatic flight control techniques. The development of highly reliable automatic control systems (such as landing systems) by the best engineering talent available will not solve all the problems associated with their effective utilization and will, in fact, create new problems. For many years to come, such complex systems will be man-machine systems that, at a minimum, will require a man to initiate the machine functions, monitor them, and decide when to disengage and override them. If all man-machine interfaces, including the user acceptance, are not optimum, system effectiveness cannot be optimum.

The principal attempt to optimize interfaces is through good human engineering design. However, traditional human engineering--usually performed after the system has been designed and the breadboard equipment developed by engineers--has been applied as if man were perfectly rational, and as if it were only necessary to consider such aspects of man as his perceptual and motor capabilities. In actual fact, however, it is equally, if not more, important to consider man's potential attitudes toward the system and to realize that these attitudes are influenced by his fears, anxieties, aspirations, and social customs. If the user acceptance is poor and performance is degraded, then coercion or appeals to pride, team fellowship, or patriotism may serve as poor seconds. On the other hand, if systems are designed initially with high acceptability just as they are with high reliability, then less human maintenance is required just as less hardware maintenance is required, and an optimal manned system is possible.

In summary, this section has briefly discussed the philosophy that all complex military systems are manned, that there is such a thing as an optimal manned system, and that the compatibility between the operational system demands and man's unique capabilities and limitations--physical, physiological, behavioral, and attitudinal--can impact system performance and cost. For an optimal manned system to result from a system development program, human factors considerations must be an integral part of the acquisition and development process throughout.

The first part of this chapter has attempted to provide a simple rationale for the inclusion of human factors considerations (by human factors professionals) in system development, the remaining sections of this chapter will address three major implementation questions:

1. Are there opportunities for human factors in system development?
2. Do we use what we know about human factors?
3. Are human factors contributions affordable?

Are There Opportunities for Human Factors in System Development?

It has already been offered that human factors as a profession has data and methods to offer which will effectively impact system cost, capability, and compatibility. The question remains as to how these prescriptions are to be influential. One might even question the feasibility of achieving partial implementation. The technical core of an answer to these questions is presented in Chapter 3. However, it is a useful transition to consider the opportunities for implementation at this point from a preeminently human factors point of view. Such a point of view can be simply summarized by a table taken from Johnson and Baker (1974). It follows as Exhibit 2-7. Basically, this chart simplifies the weapon system acquisition process and identifies a number of human factors problems (or requirements for human factors input) during the development of a complex system. Chapter 3 provides the more formal and more official requirements.

Given that there are opportunities, are human factors data and methods used? That is the next question.

Exhibit 2-7

Human Engineering Problems in Weapon Systems

Stage of System Life	Source of Problem Recognition
Preparation of System Requirements	Review of requirements. Abstract and analytic, rather than empirical. Criteria identification.
Conduct of Design (or Feasibility) Study	Study of alternative approaches.
	Preparation of outline of functions to be performed. Delineation of data relevant to these functions.
	Preparation of flow charts, or other detailed summarization, to describe the functions.
	Performance of capabilities analysis. State-of-the-art/ State-of-the-people determination.
Development Planning	Allocation of functions within the defined system boundaries (man can do better/computer can do better determinations).
	Linking together the functions in the system. Net work determination.
	Assignment of functions by type of individual involved.
Design of Development Model	Preparation of performance descriptions; task analytic job description.
	Analysis of individual workloads.
	Study of individual interactions.
	Delineation of groups' personal space (by function).
	Delineation of individual's workspace layout within group.
	Determination of location of system components.
	Study of alternative personal space layouts.
	Analysis of human information requirements.
	Analysis of human response requirements.
	Design of system interfaces.
	Determination of auxiliary job supports.
	Delineation of procedures.
	Study of equipment integration for simplification.
Evaluation of Prototype (Breadboard) Model	Evaluation through mockups and, eventually, prototype systems.
Production Model	Evaluation of system (engineering and procedures) change proposals.

(From Johnson & Baker, 1974.)

Do We Use What We Know About Human Factors?

The true "golden era" of human factors occurred from the early 1950s to the early 1960s when, among other events, there were always four or five major electronic systems under development by the Air Force. From the mid-1960s to the mid-1970s, however, the pattern has been one of decline and deterioration. It is legitimate to ask why.

There appear to be many reasons why human factors contributions have been questioned and why the human factors knowledge has not been applied to systems or accepted by system sponsors. Some of these reasons appear to be organizational factors, personnel factors, management factors, communication factors, and a host of other factors which are not directly germane to this project. Nevertheless, those reasons and others may derive from the basic problem facing human factors in the military: that the human factors researcher and practitioner are too frequently called in <u>after</u> system design and development has proceeded to a point where costly redesign and retrofit is necessary to implement human factors recommendations. This is the biggest complaint of researchers and practitioners who believe they have something of value to offer. Therefore, it seems worthwhile to examine in detail some aspects of the problem of waiting too long to integrate human factors into the weapon system acquisition process.

First of all, the question should be asked: Is this really a problem? The results of a survey (undated) conducted by Meister and received in July 1979 indicate that the problem still exists. Meister surveyed the three major participants who determine how much human factors R&D is done and how it is perceived. These participants are R&D laboratories, R&D contractors, and human

factors practitioners in the defense industry. Two excerpts from Meister's paper that deal with the practitioners' answers, and one from his Conclusions section serve, we believe, to make the point that human factors is largely unaccepted at present in system design and development:

> . . . Nor do design engineers tend to solicit the assistance of practitioners. 76% of respondents agreed with this statement. Again, there are individual variations, special individuals and special circumstances but the armed neutrality between designer and practitioner seems the same as it was when it was described in 1967 (Meister and Farr). A key element in securing designer cooperation appears from respondents' comments to be supportive management. A number of factors appear to explain the designer-practitioner relationship: the designer's wish to function with complete autonomy; his view of HF requirements as more constraints he must put up with; the HF group's reputation. It is helpful if the HF group has sign-off on man-machine interface drawings, but few groups have this sign-off.
>
> Slightly more than half (57%) of practitioners feel that there is still considerable resistance on the part of designers to the inclusion of HF inputs in design. The positive side is that almost half (41%) do not agree with this notion. It may be that these responses suggest that things are improving somewhat, because in years past almost all practitioners would have given negative answers on this point. Some practitioners feel that if behavioral inputs are reasonable, engineers will accept them. Unfortunately some HF inputs are inadequate and this creates resistance to or rather avoidance of the inputs. Timing is all-important; inputs made after decisions have been reached by designers will be resisted.
>
> This resistance may result in part from the fact that engineers may find HF inputs to design insufficiently precise and quantitative. 72% of the practitioners felt this to be the case. Some pointed out that HF data must be translated by practitioners into specific design terms or else the input is merely an additional burden to the engineer. It is clear that there is continuing

and increasing pressure to justify the utility of behavioral R&D. While this may not be unfortunate in and of itself, it does lead to a number of unfortunate results: faddism; impatience with studies whose effects are slow to emerge; unwillingness to invest research resources where results are risky.

A second point to be made concerning the lack of human factors integration and application early in system design and development can be drawn from a consideration of the military test and evaluation program. In June 1978, the Office of the Under Secretary of Defense held the 12th Training and Personnel Technology Conference (TPTC) with the topic for review "Human Factors in Weapon Systems Test and Evaluation (T&E)." The minutes of this meeting are reported in Taylor (1978). Colonel Henry L. Taylor, the Executive Secretary of the Conference, and Dr. Jesse Orlansky, a consultant from the Institute for Defense Analysis who provided written comments on the meeting, make some interesting observations concerning test and evaluation and human factors. In particular, the discussion centered on information drawn from "The FY 79 Department of Defense Program for Research, Development, and Acquisition," 1 February 1978, Chapter 9, Test and Evaluation. In the summary of the minutes, Colonel Taylor pointed out:

1. Sixty-one major programs will undergo T&E in FY 1979, and DOD will monitor a total of 84 major weapon systems.

2. The budget request for T&E in FY 1979 is $3,683 million for development, engineering and testing, and $1,009 million for support of ranges, test facilities, targets and joint tests, for a total of $4.7 billion for T&E in FY 79.

3. The following areas are now being emphasized by the DOD T&E program:

   a. reduction of vulnerability of weapon systems

b. reliability improvement of weapon systems

c. greater commonality and standardization of weapon systems among military services and with our European allies (e.g., HARM, STINGER, TRITAC, JTIDS)

d. conduct operational test and development test earlier in development cycle.

Joint Test and Evaluation (JT&Es) initiated in 1972 are used to evaluate the effectiveness of a weapon system in its intended operational environment and frequently uses the forces and systems from two or more Services.

Dr. Orlansky, referring to the same topic, made the following "passing comment":

> . . . the magnitude of the T&E budget ($4.7 billion in FY 79) does not, by itself, justify a larger or smaller Human Factors budget. However, $4.7 billion means that T&E is larger (more important?) than any category of RDT&E (the largest is 6.4 Eng. Development $3.9 billion); larger than any Service RDT&E program (Air Force is $4.3 billion); larger than any RDT&E authorization title (Naval Vessels is $4.7 billion); etc., etc. The real thought is whether any nominal Human Factors effort could produce more savings than comparable efforts in other areas. Perhaps yes, if someone is willing to explore the possibilities.

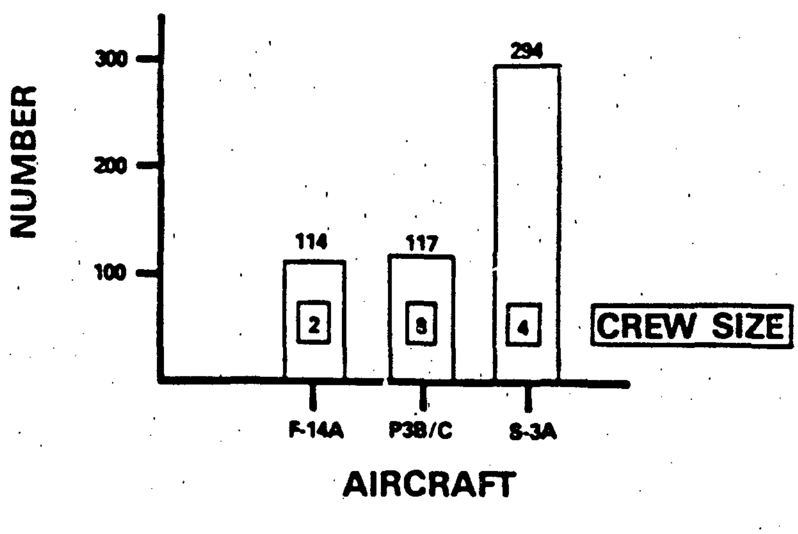
With respect to the comments made by Colonel Taylor and Dr. Orlansky, above, the point of concern is whether or not early integration of human factors in system development would preclude some of the problems (and enormous costs) associated with later test and evaluation.

Two final observations will be made concerning human factors which are "too late and too little." First of all, even after systems enter the operational forces, human factors problems still exist which are reported as deficiencies and result in costly

redesign and retrofit. It is also imperative to note that these deficiencies are not just gripes about sticky knobs, hard-to-read displays, uncomfortable crew compartments, etc., that lead to simple degraded performance in terms of time and error. Rather, some of these deficiencies include loss of life and costly equipment. As an indication of the magnitude of these deficiencies, Exhibit 2-8 is from a 1978 briefing given by the Naval Air Development Center on its human factors program. While these deficiencies only relate to three weapon systems, the absolute number of deficiencies is an indication of the magnitude of the problem.

Exhibit 2-8

Human Factors Deficiencies Report
for Several Navy Aircraft Weapon Systems*



*This chart is from a brief provided by the Human Factors Engineering Division of the Naval Air Development Center, Warminster, Pennsylvania.

The final problem observation is that in 1977 DOD announced a tailoring process for specifications and standards in Directive 4120.21. As reported by Chaikin (1978), this directive, in brief, permits: (1) selecting documents having potential application to a specific procurement; (2) reviewing those potential documents to satisfy only those clearly applicable to a contract; (3) imposing only the minimum necessary requirements; and (4) examining the surviving requirements to tailor or adjust the provisions so that they support the particular system involved. As Chaikin further observed, the same DOD Directive states "beneficial recommendations from prospective contractors shall be solicited to determine whether additional cost-effective applications and tailoring of cited . . . standard . . . requirements can be accomplished or cost-effective substitutions proposed."

This directive provides a loophole for avoiding human factors; yet, it also provides a basis for insuring the inclusion of human factors if they can be established to be cost effective.

In summary, there appear to be several kinds of constraints on the successful application of human factors to military systems development. It should be re-stressed that there is responsibility on both sides--the human factors side and the program management side--to achieve higher levels of cooperation. Most crucial is the point that near-term costs (including some real conflicts between engineering criteria and human factors criteria in design work) can result in long-term gains that are many multiples of the near-term cost.

Are Human Factors Contributions Affordable?

We have tried to indicate by means of the preceding discussion that there are at least four basic arguments for the inclusion of human factors in military system development. Each of these arguments has substantial historical roots so that they are a part of a standard rationale. In brief, these arguments are:

- Life cycle costing for personnel in a system can be impressive. Personnel must be sustained physiologically and psychologically. The cost of addressing personnel performance through training, selection, technical manuals, and other performance aids is expensive; and the cost of personnel turnover is even more expensive.

- Complexity remains a growing problem that requires a human factors contribution for its amelioration.

- Design deficiencies cause otherwise avoidable human error--such errors are costly not only in terms of lost lives and lost equipment but also in terms of unfulfilled missions.

- It is possible to conceive and implement optimal manned systems--systems that are designed to utilize human capabilities and minimize human limitations.

The response to these arguments should be:

- Human factors must lead to an increase in human reliability and consequent increase in system reliability.

- Human factors must be applied as early as possible in system development to achieve greatest cost-benefit. The cost of redesign and retrofit of weapon systems where human factors information has not been used may far outweigh the costs for human factors earlier in system design and development. However, this must be viewed as a life cycle cost.

- Human factors value will derive not just from the accommodation of human capabilities and limitations (which would typically reduce performance time and error), but also from better equipment utilization because of improved attitudes. If user acceptance is not considered in system design, the system may be underused, misused, or not used at all--which could result in mostly costs and no benefits.

- Effectively integrated human factors in systems will reduce other costs such as those for training, selection, and technical manuals.

- Lack of human factors in systems will result in damage to the equipment and in hazards to the user. In this case, incorporating proper human factors results in cost avoidance through avoidance of damage to equipment and harm to personnel.

- Human factors in system design and development will contribute substantially to system maintainability. In general, one may expect (1) time-to-maintain to go down, (2) maintenance-induced failures to go down, and (3) spare parts consumption to go down.

- Human factors consideration based on the environment in which weapon systems are to be operated and maintained will insure that human performance is not seriously degraded and, thus, that system performance will not be seriously degraded.

- Human factors integrated into the entire weapons system acquisition process and life cycle process has an intrinsic value because it becomes part of the hardware or system. Therefore, the effects of any human factors stay with the equipment or military service and reduce the cost of ownership. This is in contrast to training, in which the investment stays with the individual rather than with the equipment.

Conclusion

It is important for policymakers and program managers to realize that good human factors is not a case of just "proving the obvious," i.e., that human factors is simply common sense. In the past, a common sense approach has produced marginally acceptable system products (from a human factors point of reference) based on the fact that the hardware and technology associated with that hardware have been around for some time. Experience with it has produced a level of knowledge, one might term "lessons learned"--which is really the common sense to which we refer. In periods involving quantum leaps in technology and hardware sophistication, as we have been experiencing for some time, this common sense breaks down due foremost to the absence of "lessons learned" that comes with experience with a technology. Human factors personnel have training and experience to bring valuable knowledge and techniques to the system development process. Human factors personnel have obtained

this knowledge due largely to dealing with gaps in technology wherein common sense has broken down. In addition, operations, analysis and research in fields such as system engineering, aviation medicine, applied physiology, experimental psychology, anthropometry, and sociology have contributed a great deal of basic design data, which human factors personnel know where to find and how to interpret. Perhaps most important is the fact that human factors personnel have the necessary motivation to search for optimal solutions where man is involved.

References

Brown, H. Department of Defense annual report, fiscal year 1979. Department of Defense, 1978.

Chaikin, G. Human engineering design criteria--The value of obsolete standards and guides. Paper presented at the Human Factors Society 22nd Annual Meeting, Redstone Arsenal, AL, October 16-19, 1978.

Christensen, J.M. Ergonomics--Where have we been and where are we going? Proceedings of the 6th Congress, the International Ergonomics Association, University of Maryland, July 1976.

Coburn, R. Human engineering guide to ship system development: Responsibilities, procedures, and methods for carrying out human engineering programs (NELC/TD 278). San Diego, CA: Naval Electronics Laboratory Center, October 1973.

Department of Defense. Specifications and Standards Application. DOD Directive 4120.21, Washington, D.C., April 1977.

DePuy, W.E. The Army Training System Overview. Speech by Commanding General, Headquarters, TRADOC, 24 May 1977.

Flickinger, D.D., & Hetherington, A. Man--the Essential Factor in Systems. Directorate of Human Factors, Headquarters, Air Research and Development Command, Baltimore, MD, December 1957.

Johnson, E.M., & Baker, J.D. Field testing: The delicate compromise. *Human Factors*, 1974, *16*(3), 203-214.

Meister, D. The influence of Government on human factors research and development. Paper prepared for the U.S. Navy Personnel Research and Development Center, San Diego, CA, undated.

Meister, D., & Rabideau, G.F. *Human factors evaluation in system development*. New York: John Wiley & Sons, 1965.

A missile's ups and downs. *Time*, January 8, 1979.

Price, H.E. Job design as part of the Navy enlisted personnel individualized career system. Paper presented at the Human Factors Society Annual Meeting, Boston, MA, October 1979.

Rook, L.W. Motivation and human error (Sandia Corporation Technical Memorandum No. SC-TM-65-135). Albuquerque, NM, September 1965.

Shapiro, A., et al. Human engineering testing and malfunction data collection in weapon system test programs (WADD Technical Report 60-36). Dayton, OH: Wright Air Department Division, U.S. Air Force, February 1960.

Swain, A.D. Human factors in design of reliable systems. Paper presented at the Tenth National Symposium on Reliability and Quality Control, Albuquerque, NM, January 7-9, 1964.

Taylor, H.L. Minutes of the Twelfth Training and Personnel Technology Conference (TPTC): Human factors in weapon system test and evaluation. Office of the Undersecretary of Defense, Washington, D.C., May 11, 1978.

CHAPTER 3

IDENTIFICATION OF THE CONTRIBUTION OF HUMAN FACTORS IN SYSTEM DEVELOPMENT

In order to identify the contributions of human factors in system development it is necessary to understand both the major system acquisition and development process, and the potential for specific human factors contribution in each phase of this development process. Therefore, the first section of this chapter summarizes: the major system acquisition process, requirement at the DOD level for human factors R&D, and requirements at the service level for human factors R&D. The material in this section may be familiar to some readers, and therefore is sufficient as a refresher. However, for the less familiar reader, a separate research note (ARI RN-80-23) is available which provides a review of essential decision points, products, directives, and other requirements that govern system development and enable human factors R&D. This document may be obtained through DTIC. The significant conclusion that emerges from this summary and review is that there is an adequate and formal basis existing for integrating human factors R&D into military systems, but in fact this is not being done.

The second section will delineate specific human factors efforts in each system development phase and indicate how these efforts contribute to the development of the principal human factors product of that phase. The relationship between human factors efforts/products and system development activities is documented in the form of a graphic descriptive model.

The remaining five sections of this chapter describe in detail the human factors efforts and system development activities, the nature and content of the principal human factors product, and an example of human factors contribution for each development phase.

Prior to addressing these major topics of the chapter it is necessary to reconfirm the notion of principal human factors products in systems development. In Chapter 1 it was asserted that there is indeed a principal human factors product that will result from human factors efforts during each major phase of system development.

Exhibit 3-1 delineates these products for each phase, together with an indication of their potential effect on system design. These products were essentially derived from several studies or papers concerned with concepts or models for suggesting *what* human factors efforts, decisions, and products should be undertaken *where* in the system development phase. In general, the principal human factors products identified in this report represent a reasonable consensus of these other studies. Some representative documents from which these products were developed include Price (1962); Price, Smith, and Behan (1964); Erickson, Miles, and Secrist (1978); Goclowski, King, and Ronco (1978); and Baker, Johnson, Malone, and Malone (1979). The rationale and precedent for these products is established in more detail in Appendix A for the interested reader.

Exhibit 3-1

Principal Human Factors Products for Major System Development Phases

System Development Phase	Human Factors R&D Principal Product	Potential System Design Effects
Mission Analysis Phase	Development of the Role of Man as part of a Mission Element Needs Statement (MENS)	(a) Maximum mission flexibility (b) Maximum crew acceptance (c) Minimal crew size and costs (d) System recoverability
Concept Development Phase	Allocation of System Functions to Man as part of the Decision Coordinating Paper (DCP)	(a) Balanced automation (b) Mission sustainability/endurance (c) Optimum response to emergencies (d) Responsiveness to change
Demonstration and Validation Phase	Task Analysis and Determination of Human Factors Engineering Requirements	(a) High quality decision making (b) Productive and satisfying job designs (c) Minimal training costs (d) Minimal maintenance costs (e) Minimal retrofit and redesign
Full-Scale Development Phase	Design of the Optimal Man-Machine Interfaces	(a) Minimal response delays (b) Optimal accuracy/reduced errors (c) Optimal survivability (d) Optimal user compatibility

Human Factors R&D: The Existing Basis in System Acquisition

This section of the chapter is a brief overview of the major system acquisition/development process and the existing basis for human factors R&D at the DOD level and at the service level. As was mentioned previously, a more detailed analysis of this topic is provided in a separate research note available through the DTIC.

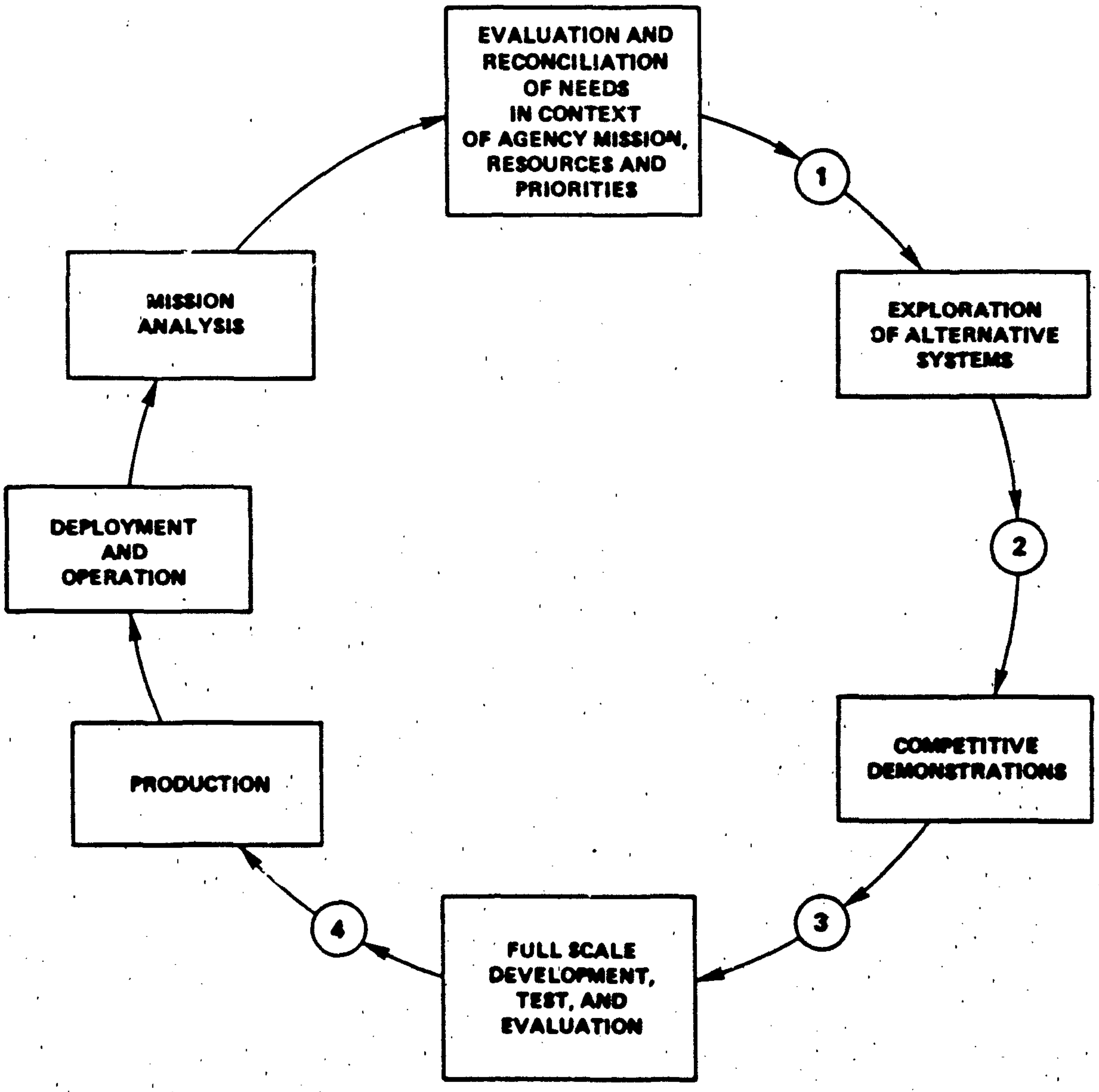
The Major System Acquisition Process

OMB Circular No. A-109 (1976) establishes the guidelines and policies for major governmental acquisitions. The circular outlines the required sequence of activities through which the proposed system must pass, and specifies the key decision points at which the evolving system must gain approval before the government will continue to fund a developing system or to procure any new major system. DOD Directives 5000.1, 5000.2, and 5000.3 give the military services more detailed instructions in implementing Circular A-109 for the acquisition of major military systems. A general discussion of Circular No. A-109 will be followed by a short discussion of the directives.

OMB Circular No. A-109. The policies in Circular No. A-109 attempt to systematically integrate the various factors in system development and to avoid past problems of cost overruns and premature commitments to full-scale development and production. To accomplish this, the circular outlines seven activities and specifies four major decision points. Exhibit 3-2, adapted from OFPP Pamphlet No. 1 (1976), shows these activities and decision points. The boxes describe the types of activities involved and the numbered circles indicate the major decision points. This acquisition model requires an identification of a need (Mission

Exhibit 3-2

The Activities and Decision Points of OMB's Circular No. A-109 Major System Acquisition Cycle



Analysis), a comparison between the present technology status and what is needed (Evaluation and Reconciliation of Needs), a decision to continue or stop ①, a study of the strengths and weaknesses of alternative systems if the previous decision was to continue (Exploration of Alternative Systems), a decision to continue or stop ②, a demonstration of the chosen system(s) (Competitive Demonstration), a decision to stop or continue ③, the building and test of the complete system (Full-Scale Development), a decision to stop or continue ④, the production of the system (Production), and field use of the system (Deployment and Operation). The Department of Defense directives specify the activities within the phases in more detail.

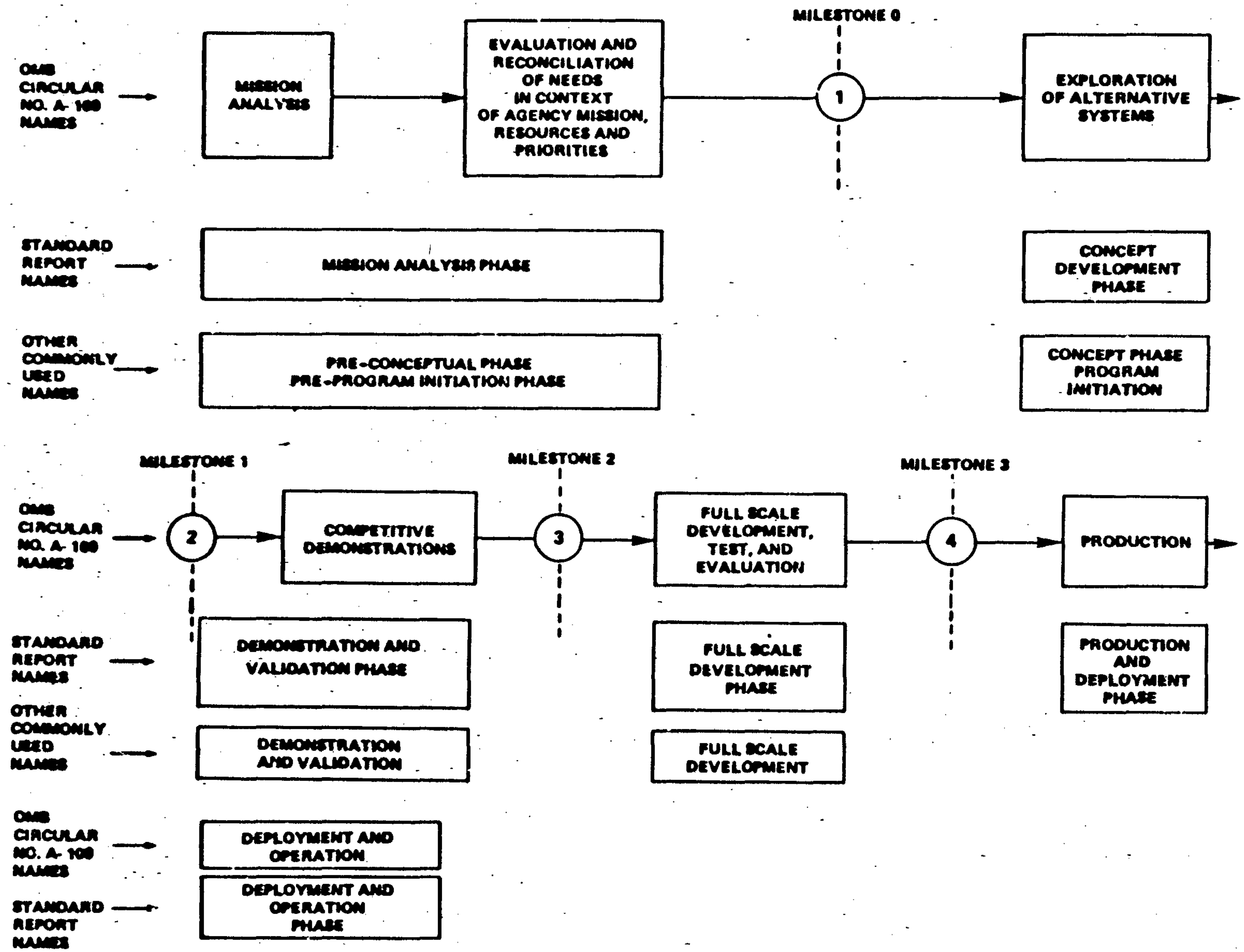
<u>Department of Defense Directives</u>. The Department of Defense (DOD) Directives 5000.1, 5000.2, and 5000.3 give guidance in implementing OMB Circular No. A-109 for military systems.

DOD Directive 5000.1 provides policy for acquisition of major systems--those systems exceeding $75 million for research, development, test and evaluation, or those systems exceeding $300 million for procurement. Directive 5000.2 supplements 5000.1 with policies and procedures for the DOD system acquisition process. Directive 5000.3 gives guidance for military test and evaluation. These three directives provide for five events and describe the activities in the phases between those events. Those five events are identification of mission needs, Milestone 0, Milestone 1, Milestone 2, and Milestone 3.

Because the circulars, directives, military standards, and service regulations used various names for the same phases, it became necessary to adopt standard phase and decision point names to avoid confusion when using information from the different documents. In Exhibit 3-3, the major system acquisition cycle

Exhibit 3-3

A Comparison of Names Used for the Major System Acquisition Model



model of Circular A-109 is again shown. Below that model are the standard names adopted for this report. Below the standard names are other names commonly used in various documents to refer to the same phases.

The military major system acquisition model as described by the directives is in Exhibit 3-4. The model spans the time from initial threat analysis to deployment of the system.

Revised Department of Defense 5000 Series Directives

Revised Department of Defense 5000 series directives were obtained just before production of the final technical report. These latest revisions do not affect the case that can be made for human factors R&D requirements in the military acquisition process. Rather than substantially changing the relationship of these DOD documents to requirements for human factors R&D in systems acquisition, they serve instead to effectively augment this relationship. Selected excerpts with human factors R&D implications are shown below to illustrate the characteristics of the new directives.

DODD 5000.1 Major System Acquisition 19 March 1980

Objectives

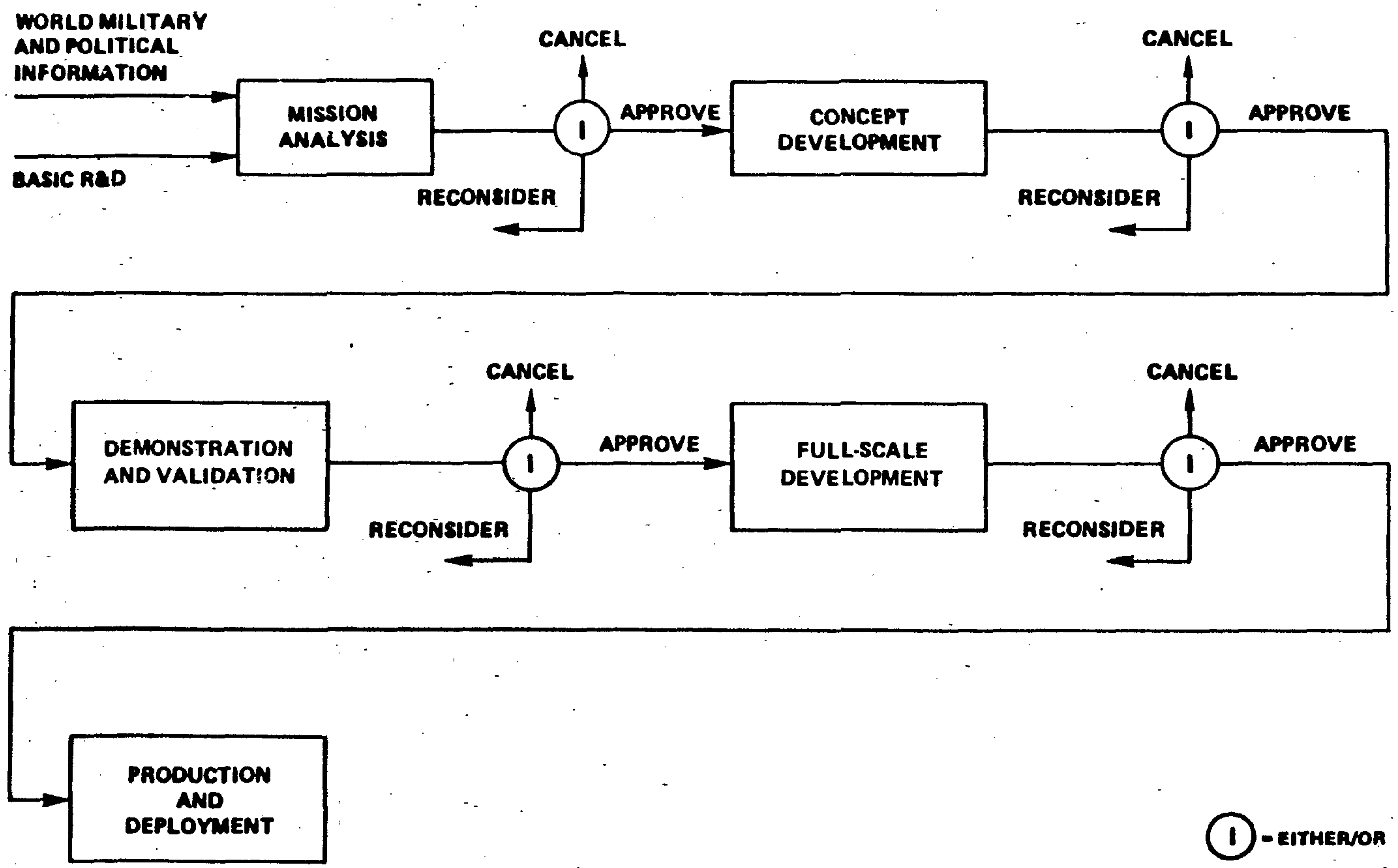
Integrate support, manpower, and related concerns into the acquisition process.

Policy

Affordability. Affordability, a function of cost, priority, and availability of fiscal and manpower resources, shall be established and reviewed in the context of the PPBS process . . . .

Exhibit 3-4

The Phases of the Military's Major System Acquisition Model



DODD 5000.2 Major System Acquisition Procedures
19 March 1980

Design Considerations

Manpower and Training

(1) New systems shall be designed to minimize both the numbers and the skill requirements of people needed for operation and support, consistent with system availability objectives. Manpower and personnel factors, to include numbers, occupations, and skill levels of manpower required, shall be included as considerations and constraints in system design. Integration of manpower and personnel considerations with the system shall start with initial concept studies and shall be refined as the system progresses to form the basis for crew station design, personnel selection and training, training devices and simulator design, and other planning related to manpower and personnel.

(2) Where applicable, planning for training shall consider provisions for unit conversion to the fielded system and training of reserve component personnel. Such planning shall consider tradeoffs conducted among equipment design, technical publications, formal training, on-the-job training, unit training, and training simulators and shall develop a cost-effective plan for attaining and maintaining the personnel proficiency needed to meet mission objectives.

(3) After Milestone 0, manpower requirements shall be subjected to tradeoffs with system characteristics and support concepts. Manpower goals and thresholds consistent with projected activity levels, maintenance demands, and support concepts shall be identified by Milestone II. Tradeoffs for maintenance effectiveness among manpower (numbers, occupations, and skill levels), support equipment, system design, and the support structure shall be conducted. The manpower and training requirements to support peacetime readiness objectives and wartime employment shall be developed by

Milestone III. These requirements shall be based upon considerations that include available Operational Test and Evaluation results and current field experiences with similar equipment.

Quality. A quality program shall be implemented in accordance with the criteria and procedures set forth in DOD Directive 4155.1 (reference (j)) to ensure user satisfaction, mission and operational effectiveness, and conformance to specified requirements.

DODD 5000.3 Test and Evaluation 26 December 1979

Policies and Responsibilities

Test and evaluation (T&E) shall begin as early as possible and be conducted throughout the system acquisition process to assess and reduce acquisition risks and to estimate the operational effectiveness and operational suitability of the system being developed. Meaningful critical issues, test objectives, and evaluation criteria related to the satisfaction of mission needs shall be established before tests begin.

Before the Milestone III decision, adequate DT&E shall be accomplished to ensure that engineering is reasonably complete (including survivability/vulnerability, compatibility, transportability, interoperability, reliability, maintainability, safety, human factors, and logistics supportability), that all significant design problems have been identified, and that solutions to these problems are in hand.

Attachment 1 - page 2 Definitions

Operational Suitability. The degree to which a system can be satisfactorily placed in field use, with consideration being given availability, compatibility, transportability, interoperability, reliability, wartime usage rates, maintainability, safety, human factors, manpower supportability, logistic supportability, and training requirements.

As these quotes aptly illustrate, the requirement for human factors has been reinforced with more direct and to-the-point statements regarding the role of human factors in system development.

With reference to DOD-level requirements for human factors R&D, it should be stated that DOD maintains one human factors specification (MIL-N-46855) and one human factors standard (MIL-STD-1472), each containing extremely detailed human factors requirements.

Formal and Informal Requirements for Human Factors R&D at the Service Level

Each service within the Department of Defense maintains its own implementation procedures for human factors requirements. These requirements, found in various service documents, may be broken up into two categories. Human factors efforts stated as requirements can be designated formal documents. Formal documents consist of the service regulations and instructions (i.e., Army Regulation AR 602-1; Air Force Regulation AFR 800-15; and Department of the Navy instruction NAVMATINST 3900.9). On the other hand, human factors efforts described as recommendations can be termed informal documents. Informal documents consist of the various service guidebooks, handbooks, manuals, etc., that have been developed.

The following points can be made about these service-level documents.

- The trend in formal documents is to define requirements and responsibilities for human factors without placing constraints upon the methodology, analysis, and data characteristics used in research.

- The informal documents cover primarily those topics not promulgated in the formal requirements.
- The consistent thread running throughout the entire service doctrine is the application of human factors as a total system concept, encompassing earlier and more detailed involvement in major military system developments.

Greater detail and technical explanations of these formal and informal service-level documents may be found in the aforementioned research note. The following sections will serve to illuminate specific human factors R&D efforts, for each system development phase, which are considered ideal in any military system development.

Human Factors R&D: Specific Efforts for Each System Development Phase

There is an ever-increasing disparity between the complexity and sophistication of modern military weapon systems and the capabilities of the military personnel. The complexity and sophistication of modern military hardware is increasing at a rate greater than ever before, while the capability of our military personnel to operate and maintain these systems is, by even the most optimistic accounts, just barely keeping pace. This hardware-personnel mismatch places a greater-than-ever burden on human factors to contribute a favorable impact on capability, cost, and compatibility.

Human factors provides information that not only affects equipment design, but also helps determine the design of personnel selection, training, and organizational structures that will make equipment more cost-effective within an operational system. Above all, human factors is concerned with the mission

objectives of an equipment system, and with actions that will assure the ability of people and machines to meet those mission objectives.

Human factors should begin by analyzing mission scenarios that are expected to be encountered in combat. Analysis is performed to identify the critical roles men will play to succeed with any particular mission. Those roles will be broken down into functions, which can then be simulated or performed under the expected operational conditions, so as to evaluate equipment designs, determine manpower requirements, forecast training requirements, and detect the organizational structures that will be required to support the equipment. Alternatively, prototype equipment and organizations can be tested empirically by field trials, in which the intended user population attempts to perform the required mission scenarios. Such tests have recently been performed for several pieces of equipment during the operational tests (OT-I, -II, or -III) required by the Life Cycle System Management Model. They have provided valuable data about equipment and organizational design, in time to (1) preclude defects that would have degraded mission performance, and (2) prevent the need for expensive modifications once the equipment was fielded.

Finally, human factors identifies support requirements. One of its important tasks is to assure that such needs as maintenance equipment, training programs, and training devices are ascertained soon enough, so that when the equipment is delivered it can be fielded promptly as part of an integrated man-machine system.

Exhibit 3-5 shows the major activities of the system acquisition cycle on a time line from Mission Analysis Phase to Deployment. Concurrent with the system acquisition time

Exhibit 3-5

Specific Human Factors Efforts and Products for Each Military System Development Phase

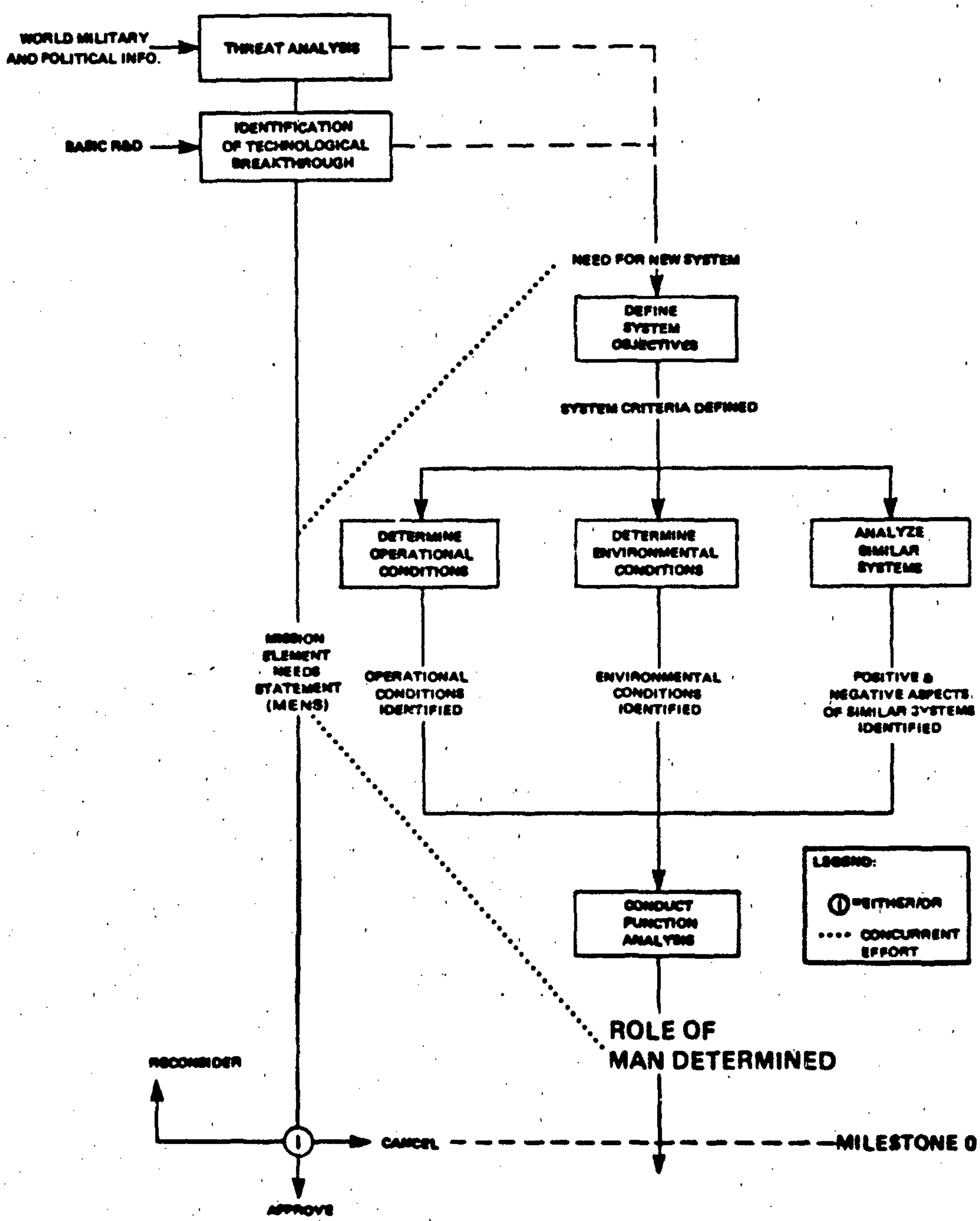


Exhibit 3-5 (Continued)

Specific Human Factors Efforts and Products for Each Military System Development Phase

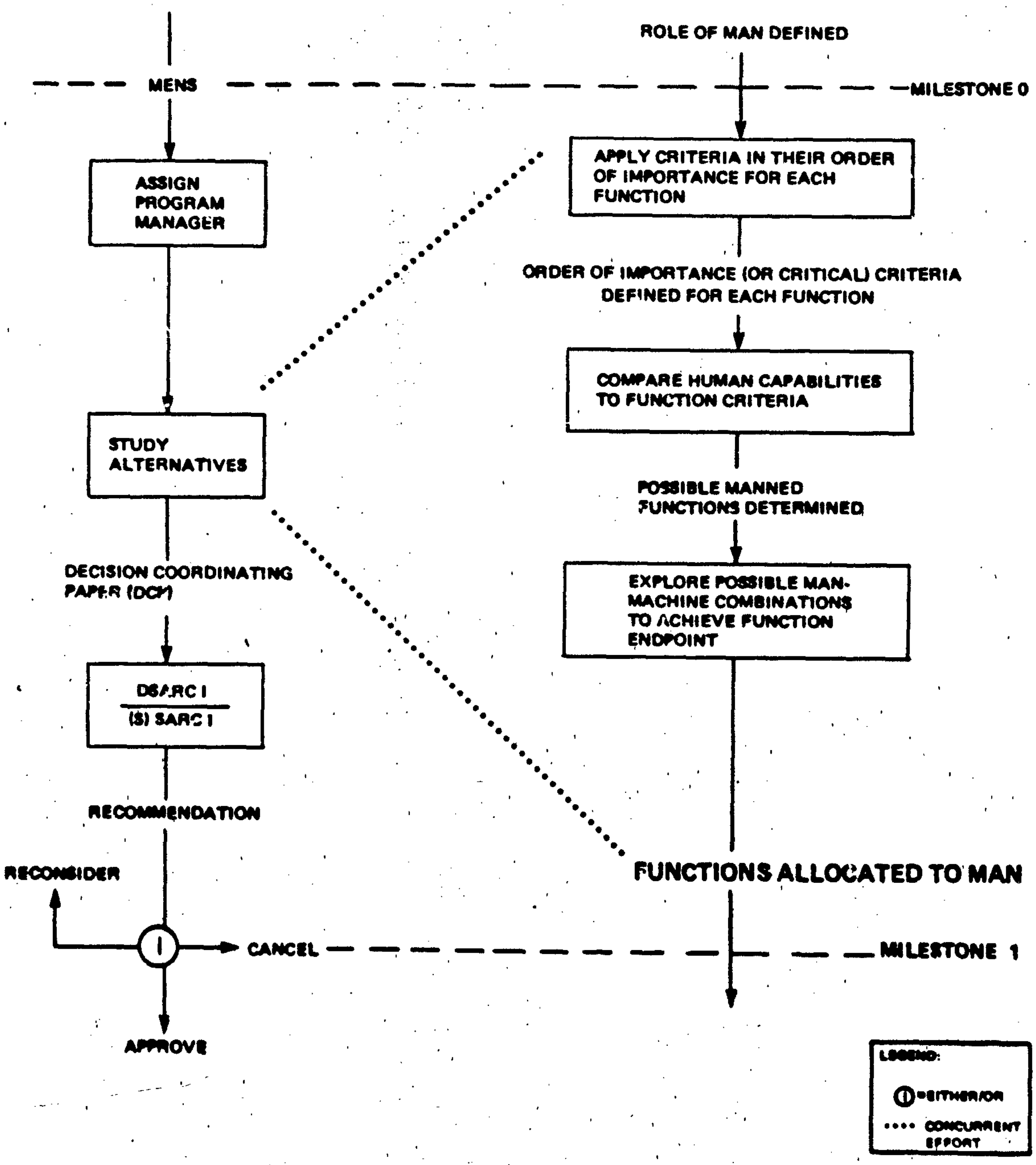


Exhibit 3-5 (Continued)

Specific Human Factors Efforts and Products for Each Military System Development Phase

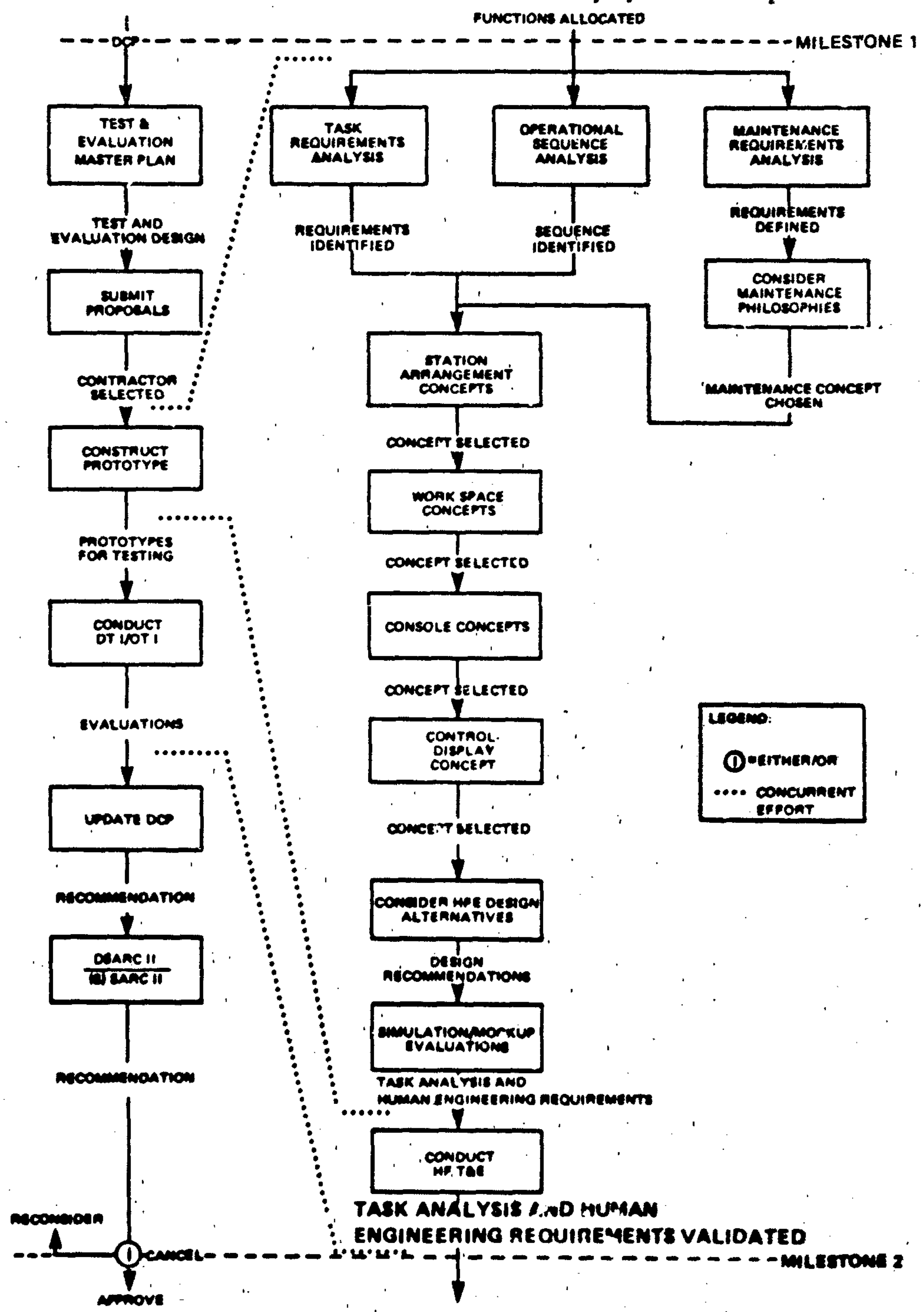


Exhibit 3-5 (Continued)

Specific Human Factors Efforts and Products for Each Military System Development Phase

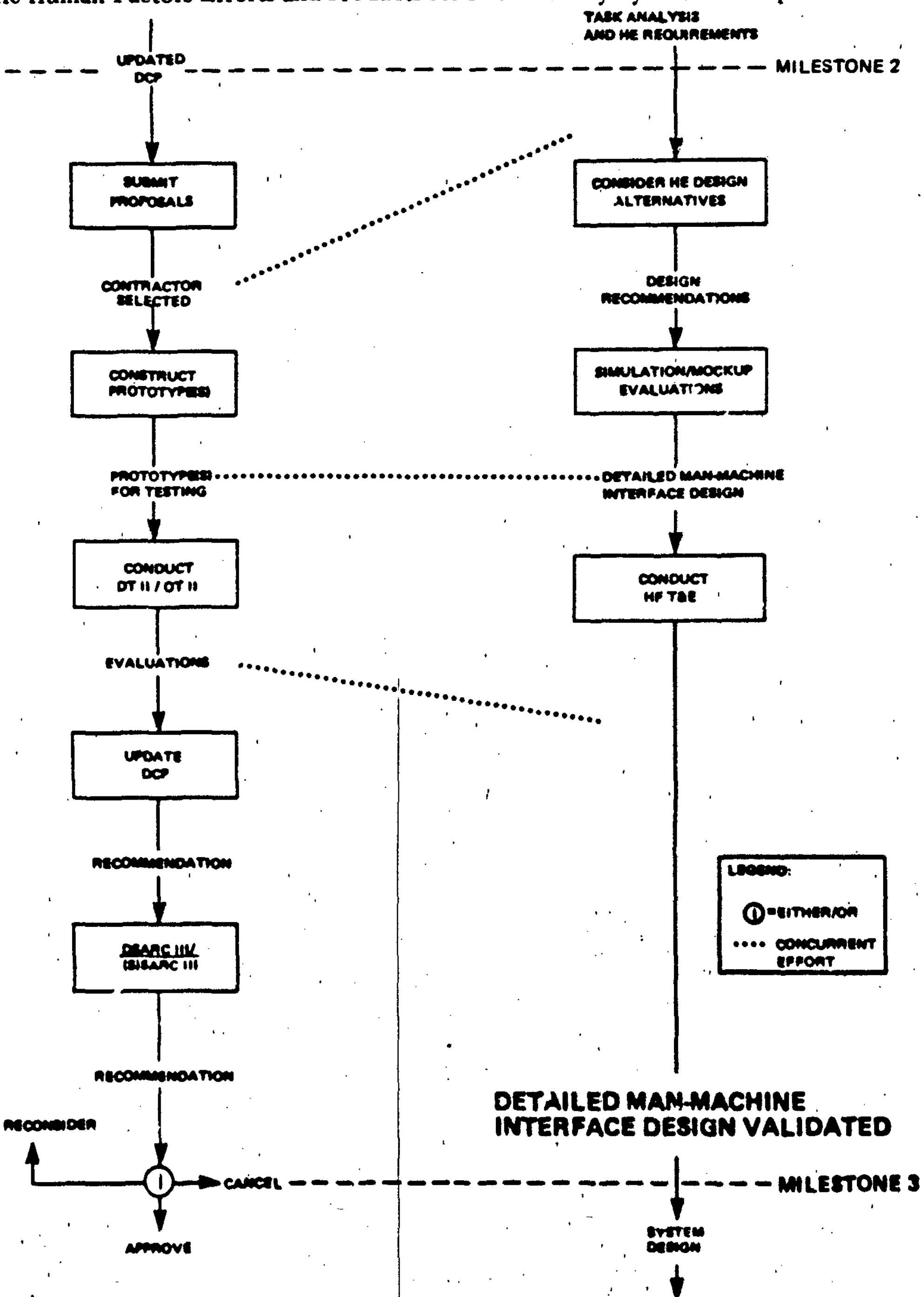
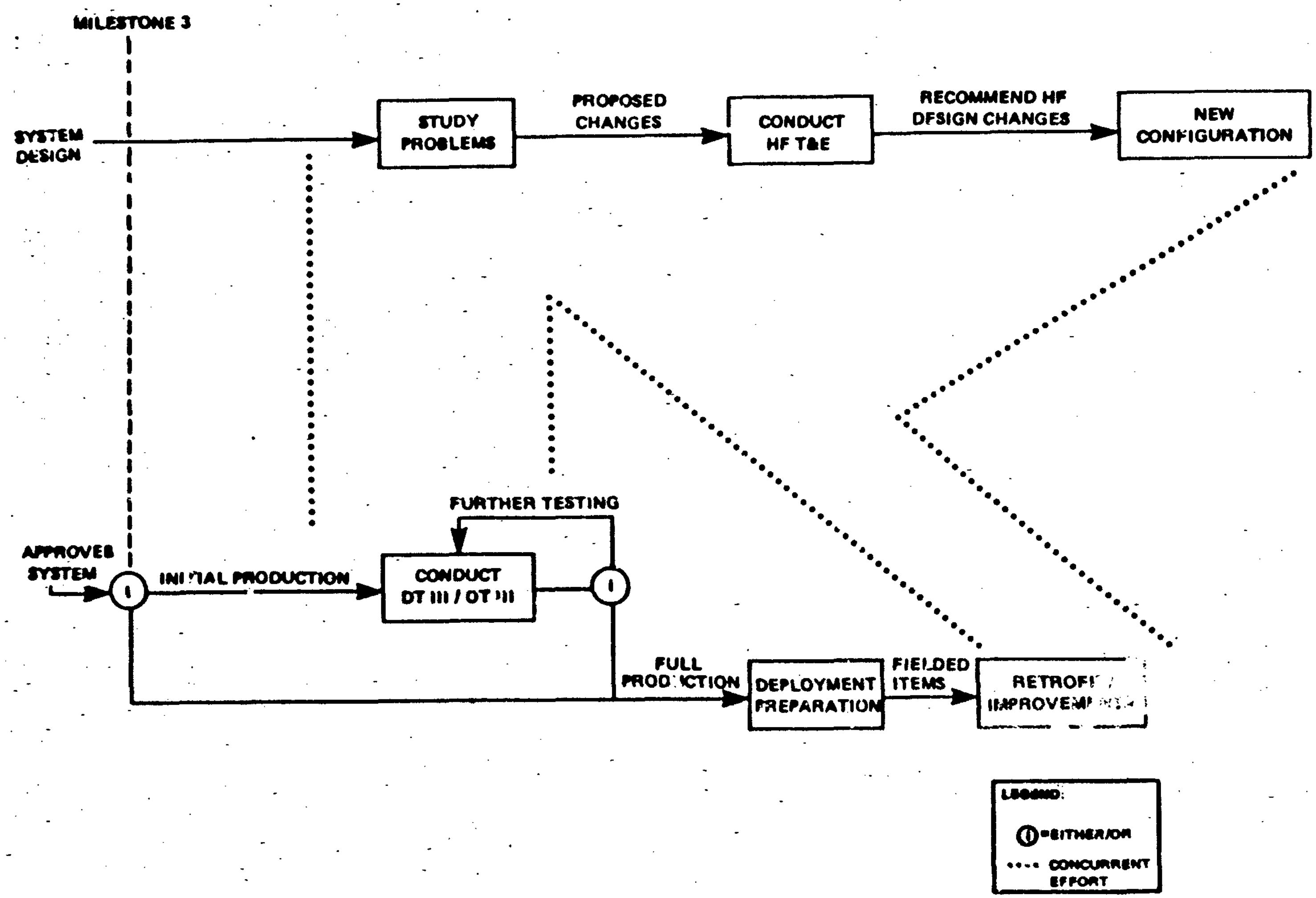


Exhibit 3-5 (Continued)

Specific Human Factors Efforts and Products for Each Military System Development Phase



line are the human factors efforts in each phase and their expected outputs. The principal human factors product of each phase is indicated by the bold type. Together, the series of charts making up Exhibit 3-5 can be considered a descriptive model of human factors efforts/products in system development.

The material to follow discusses, for each phase of system development, how human factors should be utilized as a system progresses through each phase. The human factors efforts within each phase will be described, the content of the principal human factors product of each phase delineated, and examples presented. The objectives of human factors R&D are to ensure that military equipment and organizations are well-fitted to human users and produce the maximum advantage in terms of the military's mission.

This model is a generalized one, synthesized from many sources;* it is non-service-specific, and applicable to a wide variety of systems. However, the model cannot and does not represent a rigid process of development for all systems. As with any model, there are qualifiers. While the order of human factors considerations should be maintained for most developing systems, there most likely would be variations in which phase the specific human factors considerations would be addressed.

Depending upon the complexity, operational environment, crew role and size, number of manufacturers, etc. involved in developing the system, the resolution of specific human factors efforts may shift from one phase to another. In other cases, the developing

*Principal reference sources for development of the model depicted in Exhibit 3-5 were: Baker, Johnson, Malone, & Malone, 1979; Coburn, 1973; Collins, McGuiness, Erlichman, & Bryce, 1975; Geddie, 1979; Goclowski, King, Ronco, & Askren, 1978; Kaplan & Crooks, 1980; Meister & Rabideau, 1965; Merriman, 1976; MIL-H-46855B; Price, Smith, & Behan, 1964; Price & Tabachnick, 1968; Van Cott & Kinkade. 1972.

process may be compressed or specific efforts not needed, both of which could result in entire phases being eliminated. In reality, many of the human factors efforts are iterative, and the complex feedback and feedforward loops have been deleted in favor of a perceptually and conceptually uncluttered model.

Mission Analysis Phase Human Factors

When a threat or technological breakthrough has been identified and a decision made to propose a new system, the various system developers should begin a coordinated effort to clearly state the objectives and define the criteria of the system. These would not be statements on how to accomplish the mission, but rather on what is to be accomplished. These first activities are extremely important, as the criteria will become the standards for subsequent design and for test and evaluation. Once the objectives have been identified and the criteria defined, those other political, economic, and time constraints that bound the system design must be identified.

The human factors output of this phase is the determination of the role that man will play in the new system. Will man be an operator, maintainer, sensor, manager, analyzer, decisionmaker, information manager, back-up to equipment, or some mix of the above? A very important decision is whether man will be local or remote from the mission equipment. To define that role, all functions that are needed to achieve the mission objectives must be specified first. To identify all functions, the operational and environmental conditions under which the system is to operate must be determined. For example, will the system operate in temperature extremes, during day and night, in unusually rugged conditions, or for unusually sustained periods of time, etc.? In addition, analyses of existing similar systems (if any) should

help identify operational and environmental conditions as well as other positive and negative aspects. For example, what was the role of man in the predecessor or similar system(s)? What man functions and man-machine functions have been successful and unsuccessful? All of the information can be used in performing a functional analysis.

Performing tradeoff studies with the major factors (e.g., logistics, maintenance, costs, advantages and disadvantages of using man in alternative roles) should result in cost-effective system configurations, given system constraints. Such human factors analyses also lower the probability of major changes in design downstream to accommodate the idiosyncracies of man.

Human Factors Efforts and System Development Activities During Mission Analysis

This subsection provides a description of the human factors efforts and system development activities shown in Exhibit 3-6. The descriptions are keyed to the numeric code on the chart.

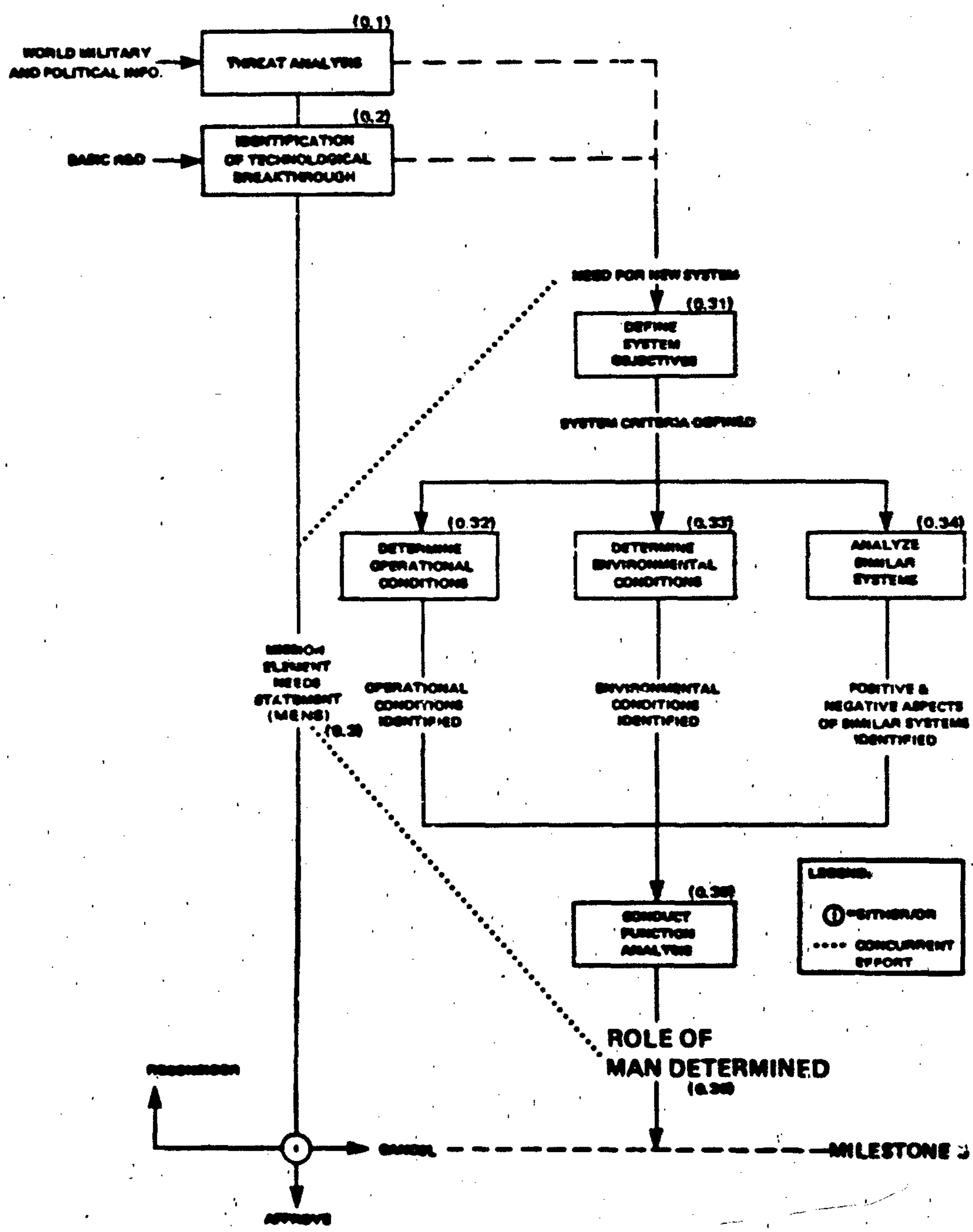
The initiation process for system acquisition is based, first and foremost, upon the demonstration of a need for a system to fulfill a to-be-specified mission. This is driven from one of two sources:

(0.1) Threat Analysis. A systematic means to assess enemy capability in relation to one's own capability to wage war. Formally defined, it is stated thus:

> The process employs analytic techniques for developing plausible alternative representations of foreign environnments and capabilities. Threat analysis--
>
> 1. Provides an assessment of foreign capabilities in terms of combat material, employment doctrine, environment and force structure.

Exhibit 3-6

Specific Human Factors Efforts During the Mission Analysis Phase (0.)



2. Provides an assessment of the level of development which the economy, the technology, and the military forces of a country have attained or could attain.

3. Includes recasting existing intelligence assessments and forecasts to provide statements of the threat as it relates to a specific U.S. research or combat development project. (AR 381-11)

(0.2) Identification of Technological Breakthrough. In an attempt to take advantage of the possibilities offered by newly or nearly available technologies an effort must be initiated. The following quote tempers the application of new technology.

> These technical and scientific advances must be evaluated within the framework of the military system developments to insure the proposed development is relevant to the DOD's needs. (Adapted from DA Pam 11-25)

(0.3) Mission Element Needs Statement (MENS). The MENS is a DOD-level required product of the Mission Analysis Phase and is aptly summarized by the following:

> The MENS provides justification for initiation of further system acquisitioning programming, addresses mission related deficiencies (e.g., capabilities change due to: change in enemy threat system obsolesences, new technology availability), provides guidance for system concepts and identifies constraints. (Adapted from SECNAVINST 5000.1A)

Requisite human factors inputs to the Mission Analysis Phase should be found in the MENS, which is the subject of the preceding discussion. The discussion to follow is the substance of human factors inputs, and culminates in the major human factors product in the Mission Analysis Phase--the role of man in systems.

(0.31) Define System Objectives. Human factors inputs must be general in nature by definition. Thus a general but valid statement of the mission(s) and threat must be developed (e.g., potential targets, enemy weapon capabilities). (Adapted from MIL-STD-490)

> The specification of mission requirements, objectives and criteria include the determination of the class system and hardware involved and a statement of the activities assigned to a system envisioned for a specific mission(s). (Adapted from Kaplan & Crooks, 1980)

Once having defined system criteria, additional descriptions must be prepared that provide a refinement of mission details. These include determination of mission constraints and limitations that impact the feasibility of continued system development.

(0.32) Determine Operational Conditions. This includes the specification of two items: (1) system operation and (2) conditions of performance. Both are important to mission feasibility.

System operating characteristics and goals must be identified to determine a probability for mission success. Personnel, crew, and hardware characteristics during performance of a mission must be defined to illustrate mission constraints that impact mission success.

(0.33) Determine Environmental Conditions. Known system characteristics, operating locus, and enemy countermeasures must be identified to reveal limitations upon various approaches to a mission. This includes a determination of terrain and climate/weather conditions.

(0.34) Analyze Similar Systems. Since most new systems rarely make use of technology never before experienced in any total sense, the analysis should encompass previously encountered strengths and weaknesses as well as lessons learned to avoid previous development pitfalls.

A process of synthesis must be utilized to incorporate the findings of the various analyses previously conducted in order to determine the overall feasibility of a system development program. In addition to system characteristics, this process should lead ultimately to a defined role for man--the master product of human factors in mission analysis (and the sole human factors reason for participation of specialists at this stage).

(0.35) Conduct Function Analysis. Function analysis, originally conceived as a process in system engineering to select functional categories for system performance (involving the techniques of functional flow diagramming and block diagramming), has been extended to include the functions of man in the system, without whom no system performance would be possible. This analysis involves the selection of manual, hardware, or automated performance for each function. The analysis stops short of allocating specific functions to man or machine, but terminates with data tantamount to such a distinction. For human factors, the interest was exclusively in assessing the capabilities of humans in any specific system.
(Portions adapted from MIL-STD-490)

(0.36) Role of Man Defined. The culmination of the preceding activities is the role of man in systems (from a human factors standpoint). Since this is a major product of mission analysis, its principal components have already been indicated and will not be repeated again.

Content of the Role of Man Statement

A statement of the role of man as part of the Mission Element Needs Statement (MENS) should include the following considerations:

Assumptions:

- A separate "role of man" analysis will be provided for each alternative system concept selected.
- Human engineers will develop "role of man" concepts and interact with mission analysis team in development of MENS.
- "Role of man" components are listed according to probable order of presentation in MENS (not according to their development sequence).

Actions:

1. List effects envisioned for overall system as a result of role of man devised for each alternative system concept as configured (e.g., operability, maintainability, mission effectiveness).
2. List effects envisioned for man's role/personnel subsystem as a consequence of each alternative system concept as proposed (e.g., safety, habitability, user acceptance).
3. Determine location of man in system to perform designated role.
4. Specify advantages accorded man's role for each alternative concept (e.g., facilitate operation of system, allowance for contingencies).

5. Specify disadvantages accorded man's role for each alternative concept (e.g., manpower reserves consumption, level of training requirements).

6. Determine required human performance, behaviors, capabilities, and performance limits (e.g., sensing, processing, information storage, decision making, responding) identified for each functional category.

7. Determine personnel constraints impacting man's role for each alternative system concept such as the following:

   a. maximum and minimum numbers of personnel who can be used in the system

   b. types of personnel (e.g., skill level and aptitude) available for system assignment

   c. anthropometry of identified personnel population (existing and projected)

   d. user acceptance problems projected and their effects

   e. effects of system and mission as configured on personnel vulnerability (e.g., environmental hazards)

   f. communication requirements and limits (system and other personnel).

8. Determine implications envisioned for each alternative system concept upon requirements for:

   a. training (e.g., level of training, trainability, training support and facilities, training devices)

b. manpower (e.g., manpower levels, performance availability)

c. life support

d. "-ilities" support (e.g., logistics, reliability, maintainability)

e. social/organizational impact (e.g., MX basing).

9. Select contributions to function analysis in Mission Analysis Phase:

   a. identification of threat

   b. need demonstration: new system or modification to current system

   c. requirement

   d. mission

   e. system objective definition (and required input/output)

   f. mission segment

   g. scenario(s)

   h. functional categories

   i. functional flow and operational event sequences

   j. system specification:

      1. manual

      2. hardwired

      3. automated: Facilitate system functioning
         Override (bypass) system malfunctioning
         Control system graceful degradation
         Permit system to operate.

10. List human factors characteristics that will facilitate successful system development and mission success for each alternative concept (design, development, testing, production, deployment, and operation):

    a. advancement in state-of-the-art human factors technology

    b. currently available human factors technology.

11. List impacts upon cost and system effectiveness for each alternative concept in association with human factors inputs:

    a. R&D, training, personnel, manpower

    b. mission success, vulnerability, survivability.

12. Prepare Human Factors R&D Program Plan tailored to each alternative concept for balance of system life cycle.

Mission Analysis Phase: Example of Human Factors Contributions

Both doctrine and recent history suggest that future warfare will require a capability to fight at night, and during operations sustained around the clock. The Soviets claim an ability to fight at night. Aside from that threat, the importance of night combat is obvious. Modern battle will move rapidly; the unit that can move and fight at night may gain a permanent advantage. Furthermore, weapons are so lethal that maneuvering at night may have great advantages in security. But unfortunately, little is known about the capabilities and limitations of soldiers during the night or in continuous operation. We lack knowledge of the mission scenarios that would be involved and therefore of how to train for battle at night. There is a requirement for research on which to base appropriate training; the development of tactical doctrine, and plans for unit rotation, performance aids, and training devices.

An example is provided by the work of the 9th Infantry Division at Fort Lewis, Washington, which was concerned with improving the ability of individual soldiers to navigate at night.

Army researchers began by analyzing the strategic goals of night operations and continuing operations. From these goals they identified specific tactical missions, analyzed the situations that would occur, and then determined the human behavioral requirements for mission success. This produced a statement of the behavioral requirements for mechanized infantry squads and platoons in a combined arms defense against a deliberate breakthrough attack. A methodology was developed in which a number of specific mission scenarios can be varied, so that the soldier's tasks occur under a variety of conditions (differing levels of light, fatigue, stress, out-of-phase daily rhythm). Tasks critical to the enemy's defeat were evaluated in terms of what behaviors they required compared with what soldiers were actually able to perform. Areas in which soldiers fell short were identified and recommendations were made concerning changes to tactics, equipment, and training.

Army researchers studied several basic issues, including the ability of soldiers who are moving in vehicles to maintain their orientation. It was found that even infantrymen on foot had a poor sense of direction at night, and lost their navigational reference. Those in personnel carriers, and the crews of armored vehicles, were substantially poorer in this regard. This fact is of special interest because current vehicles do not carry navigational aids. Study of individual differences found no way to select people based on their backgrounds, but suggested that actual experience in land navigation did improve both night and day navigation. Further research is now in progress.

Meanwhile, light-attenuating devices (LADs) were identified as a possible tool for training in nighttime operations. Ordinary darkened lenses posed a hazard: They attenuate light well only in the visible range, and transmit harmful infrared and ultraviolet light. Since the pupil of the eye responds only to visible light, the eyes of the subjects wearing ordinary goggles would be dilated, making them particularly vulnerable to damage. By using lenses with an appropriate degree of attenuation, it is possible to closely approximate visual conditions under different degrees of moonlight or darkness. The Army evaluated the goggles at Fort Rucker in flying training and at Fort Lewis in land navigation. Test results suggested a satisfactory behavioral approximation of darkness, and research continues concerning their suitability for teaching various nighttime tasks.

The use of LADs has been demonstrated for the training of tank drivers at Fort Knox, for infantry navigation at Fort Lewis, and for nap-of-the-earth night helicopter flying at Fort Rucker. Training of this kind, conducted by day, has great advantages in safety. More training can be accomplished for the time invested because supervisors and trainers can direct the activity using normal vision, and because logistics is not impeded by darkness.

The Basic Combat Training Group at Fort Jackson has implemented night rifle training using the LAD. Aside from the general difficulty in seeing, soldiers tend to overestimate range at night--an error which training can correct.

This research has provided a limited capability to train infantrymen, truck drivers, and helicopter pilots in night operations. It provides an initial scientific understanding of soldier performance at night, and contributes to building a human technology data base to help develop methods and machinery to counter a night fight threat and maximize our night fight capabilites.

Concept Development Phase Human Factors

In the Mission Analysis Phase, the system functions were identified. In the Concept Development Phase, criteria for each function are derived and rank-ordered or weighted in importance. For example, in a particular function one must determine the relative importance of accuracy, flexibility, and firing rate. In one system a fast firing rate is most important; while in another accuracy may be ranked first.

After rank-ordering or weighing the criteria, the criteria are compared to human capabilities. The comparison process should suggest which functions should be allocated entirely to machines, others entirely to man, and still others to some man-machine combination. Those man-machine functions should be further studied to determine which combinations would produce the most effective performance. It is equally poor to have a man do a job at which a machine is better as it is to have a machine do a job at which a man is better. The intent of the man, machine, and man-machine function allocation is to have the most effective participation of man, given the system constraints.

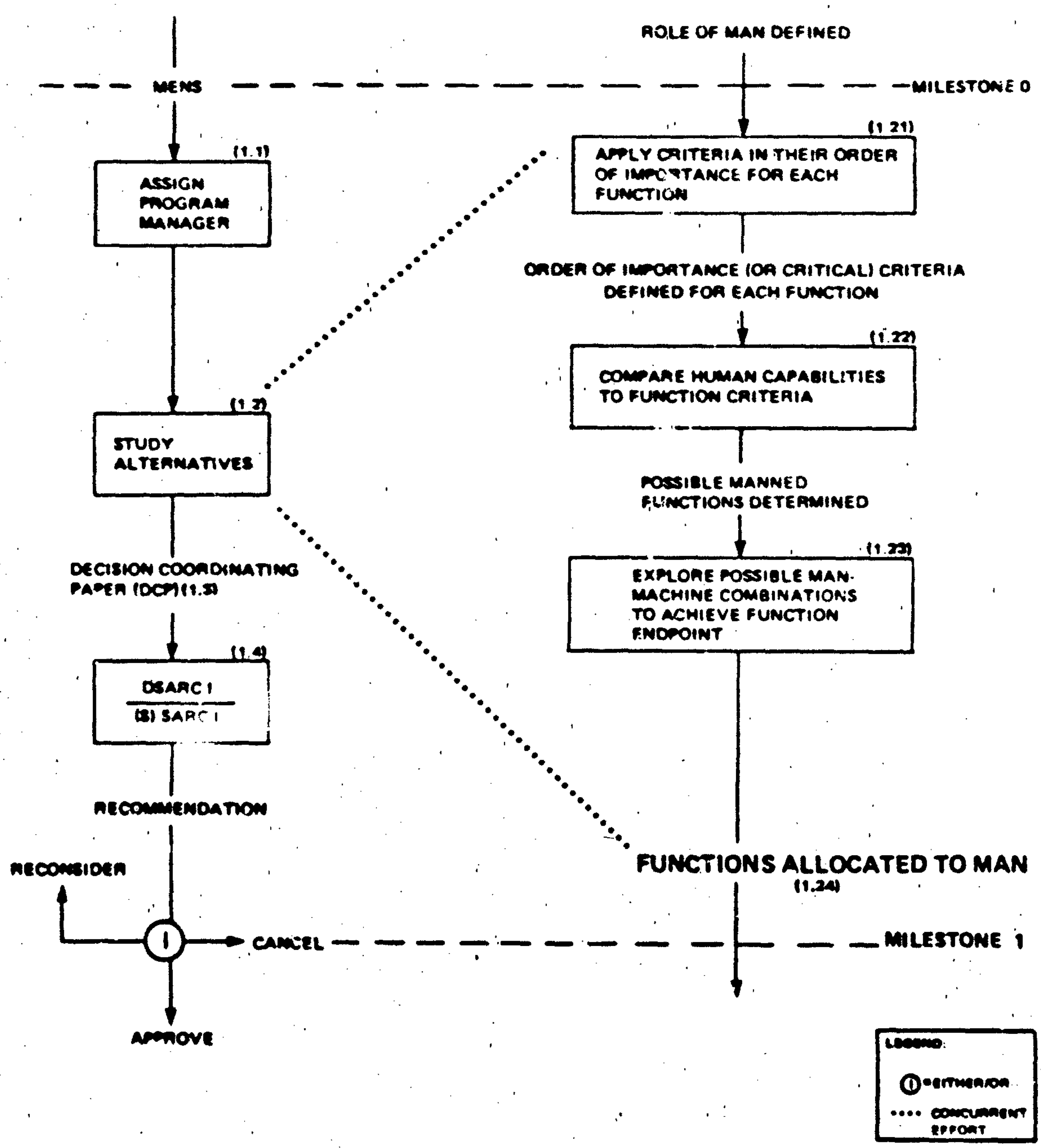
Human Factors Efforts and System Development Activities During Concept Development

This subsection provides a description of the human factors efforts and system development activities shown in Exhibit 3-7. The descriptions are keyed to the numeric code on the chart.

The major products of the Mission Analysis Phase, which includes the Role of Man in Systems, are carried forward as input to the Concept Development Phase, wherein the initial allocation of functions between men and machines occurs. Steps in system development include the following in concept development.

Exhibit 3-7

Specific Human Factors Efforts During the Concept Development Phase (1.)



(1.1) Assign Program Manager. Inherent with the designation of a system development program manager is a cluster of activities involved with management of the development life cycle (e.g., Development Plan, Decision Coordinating Paper, etc.).

(1.2) Study Alternatives. This general title includes the initiation of development of, and culminates with the verification of, the conceptual system(s). It involves the continued refinement of Mission Analysis Phase products, validation of the same, and development, study, and approval of alternative system concepts which are summarized in a Decision Coordinating Paper (DCP).

The principal human factors activities in the Concept Development Phase are directed toward the allocation of functions to man and machine. The activities involved in arriving at this product are the subject of the following discussion.

(1.21) Apply Criteria in Their Order of Importance for Each Function. This is a two-part activity. It involves (1) development of appropriate tradeoff criteria and (2) application of the tradeoff criteria to the allocation of functions between men and machines.

Examples of candidate criteria include:

- cost (procurement and operation)
- weight
- development time
- development risk
- safety
- maintainability
- system effectiveness prediction
- physical volume, size limits
- survivability.

And for human factors specifically:

- human performance capabilities and limitations
- machine performance capabilities and limitations
- special case effects of automation upon system capability.

Application of criteria can involve manual or computer-aided models, but must demonstrate:

- effects of the system upon human performance
- effects of human performance upon system effectiveness
- rationale of the decisions based upon criticality of alternative versions.

(Adapted from Coburn, 1973)

(1.22) Compare Human Capabilities to Function Criteria. After obtaining a preliminary allocation of functions to men and machines, an assessment must be made of human capability to perform effectively each function designated to man. This may involve lessons learned and other data obtainable through analysis of previous similar systems or through human performance reliability simulation by means of a number of currently available models. Whatever method is utilized, the result must be a rank order of preferred candidate manned functions along with a rationale for their choice.

(1.23) Explore Possible Man-Machine Combinations to Achieve Function Endpoint. The final activity in the analytic process of function allocation requires the analysis of candidate allocation versions (or man-machine combinations), utilizing models such as those described above, but with the intent of assessing more comprehensive performances (such as workload characteristics) rather than individual functions. The method utilized should provide a decision and associated rationale for human factors choice of man-machine combinations.

(1.24) Function Allocation. The principal product of the Concept Development Phase is the allocation of function to man and machine. This product is described in great detail elsewhere and will not be repeated here.

(1.3) Decision Coordinating Paper (DCP). DCPs are documents that support, authorize, and promulgate decisions to initiate development programs and establish appropriate Advanced/Engineering Development Line items (OPNAVINST 5000.42A). They present the rationale for starting, continuing, reorienting, or stopping a major development program. DCPs address affordability of a proposed system as well as other important factors (e.g., threat, risks, acquisition cost, strategy, and performance parameters for evaluation).
(Adapted from DA Pam 11-25)

(1.4) DSARC I/(S)SARC I. Defense System Acquisition Review Council I/(Service) System Acquisition Review Council I provide recommendations as to the status and readiness of each major system under development to advance to subsequent phases in its life cycle. They review such documents as the DCP in this process. Final decisions are made by the Secretary of Defense or his designee.

Content of the Allocation of Functions to Man Statement as Part of the Decision Coordinating Paper

A statement of the allocation of functions to man as part of the DCP should include the following considerations:

Assumptions:

- The following items will provide direct input to the specification of the function allocation process:

- Mission Element Needs Statement (MENS)
- mission scenarios
- functional flow block diagrams
- mission time lines.

- Function allocation will provide support to the proposed system by illuminating the following criteria:
  - system performance
  - cost-effectiveness.

  Both criteria have as a function human performance. Human performance can be specified according to degree of detail available about the system mission and environmental factors.

- Function allocation will detail functions involving both operators and maintainers.

- The following general process is assumed for the function allocation process:
  - identify and allocate tasks and functions to be assigned to all personnel
  - identify required equipment
  - evaluate selected man-machine combinations
  - arrange tasks and functions to maximize mission effectiveness and reliability.

Actions:

- This section is arranged according to a topical development sequence for function allocation (not development sequence).

1. Specify human factors criteria selected for allocation of functions (e.g., response time, error rate or human performance reliability, cost).

2. Specify other criteria selected for allocation of functions (e.g., cost, personnel cost, required training, weight, development time, development risk, safety, maintainability, system effectiveness, physical volume and size limits, and survivability).

3. List allocation of each function to:

   a. one or more operators/maintainers

   b. machine only (includes automation)

   c. combination of man and machine

   d. function currently not amenable to man or machine performance.

4. Multiple operator/maintainer and man/machine functions will include specification of the type of redundancy in the task being proposed (e.g., parallel or sequential mode, or hybrid of both).

5. Provide estimate of feasibility of performance for each function allocated. List the effect of different allocation versions upon mission success (e.g., probability). Provide estimate of workload upon operators/maintainers as a result of each allocation version (at least nominally). (At this level of development, workload implies task difficulty and will include requirements for: precision, concentration, criticality, mission priority, and task continuity for operators/maintainers involved in each manned function.) Account for effects of user acceptance for each allocation version.

6. List human performance capabilities required of operators/maintainers for each function involving man and verify whether or not man can perform each in terms of required physical and mental parameters over the required time period and within the anticipated environment.

7. Prepare rank orders for candidate allocation combinations according to criticality of functions. (Criteria for criticality will also be specified.)

8. List all bottlenecks, data overloads, acceptance problems, and other mission-critical faults that occur as a consequence of each allocation version. Specify the means by which each allocation version will relieve them and/or how to modify the allocation version to accommodate them.

9. Prepare a comparison matrix which exhibits all allocation versions versus the selection criteria (entries in the matrix are estimates of absolute performance or rank for each allocation version or each criterion measure).

10. List preferred manned functions as well as other combinations or allocated versions.

11. Provide a rationale for the preferred approach and selection to justify the allocation.

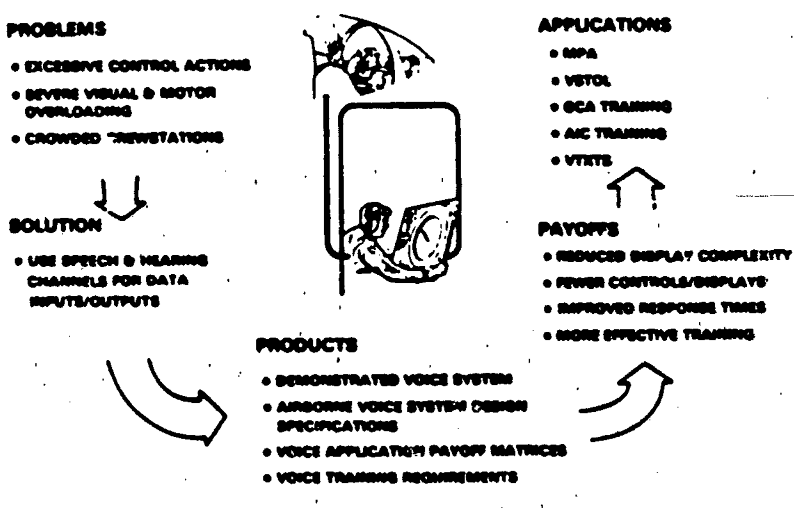
Concept Development Phase: Example of Human Factors Contributions

Navy fliers are faced with too many tasks requiring the use of eyes and hands. Excessive workload can have serious adverse effects on mission effectiveness and safety.

The workload must be reduced if the performance potential being designed into new systems (and which the operator is now too busy to fully utilize) is to be attained. New designs for airborne systems reduce crewstation crowding but do nothing to reduce workload problems because they still continue to rely solely on visual and motor task performance by the operator. The research discussed here is an effort aimed at achieving a technological breakthrough.

A technological breakthrough is being achieved by developing an alternative means of communicating with the aircraft system by the spoken word.

In general, voice systems allow the operator to input data or ask questions about the status of the system using conventional speech, and to receive verbal status advisories or warnings as well. This capability for full "interaction" by voice is called a voice-interactive system (see figure).



Voice Interactive Systems

Voice systems can reduce workload and enhance the productivity of the operator in a variety of system applications. Laboratory studies and operator estimates indicate that data can be entered into onboard computers two to three times faster by voice than by manual keyboard when the operator is performing a control (hand) or visual task at the same time. A voice system fully integrated with other weapon subsystems can reduce time to detect and respond to an emergency by 30% to 50%, depending on the operator's involvement with other tasks. Such time savings during critical mission segments could yield dramatic returns in improved mission performance.

Demonstration/Validation Phase Human Factors

In this phase, task analysis and operational sequence analyses are conducted to determine what tasks are performed in what order to accomplish each manned function. These analyses specify what information needs to be present and what types of responses are necessary for each task. These analyses also specify what skills and knowledge are required to perform the task. The results of the analyses are used to develop station arrangement concepts. The stations can represent one function of the system or a group of similar tasks from all the functions.

The work space is then developed from station arrangements. There are a number of techniques available to maximize the efficiency of the work space and decrease operating errors.

The console concept is developed from the results of the work space analysis, the information and response requirements, and task clustering. The control-display analyses deal with how the required information is to be presented and what types of controls are best for the responses.

The human factors product of this phase specifies what kinds and quality of human performance are required, and the human engineering required for operators and maintainers, including the information and response needs at each interface.

Human Factors Efforts and System Development Activities During Demonstration/Validation

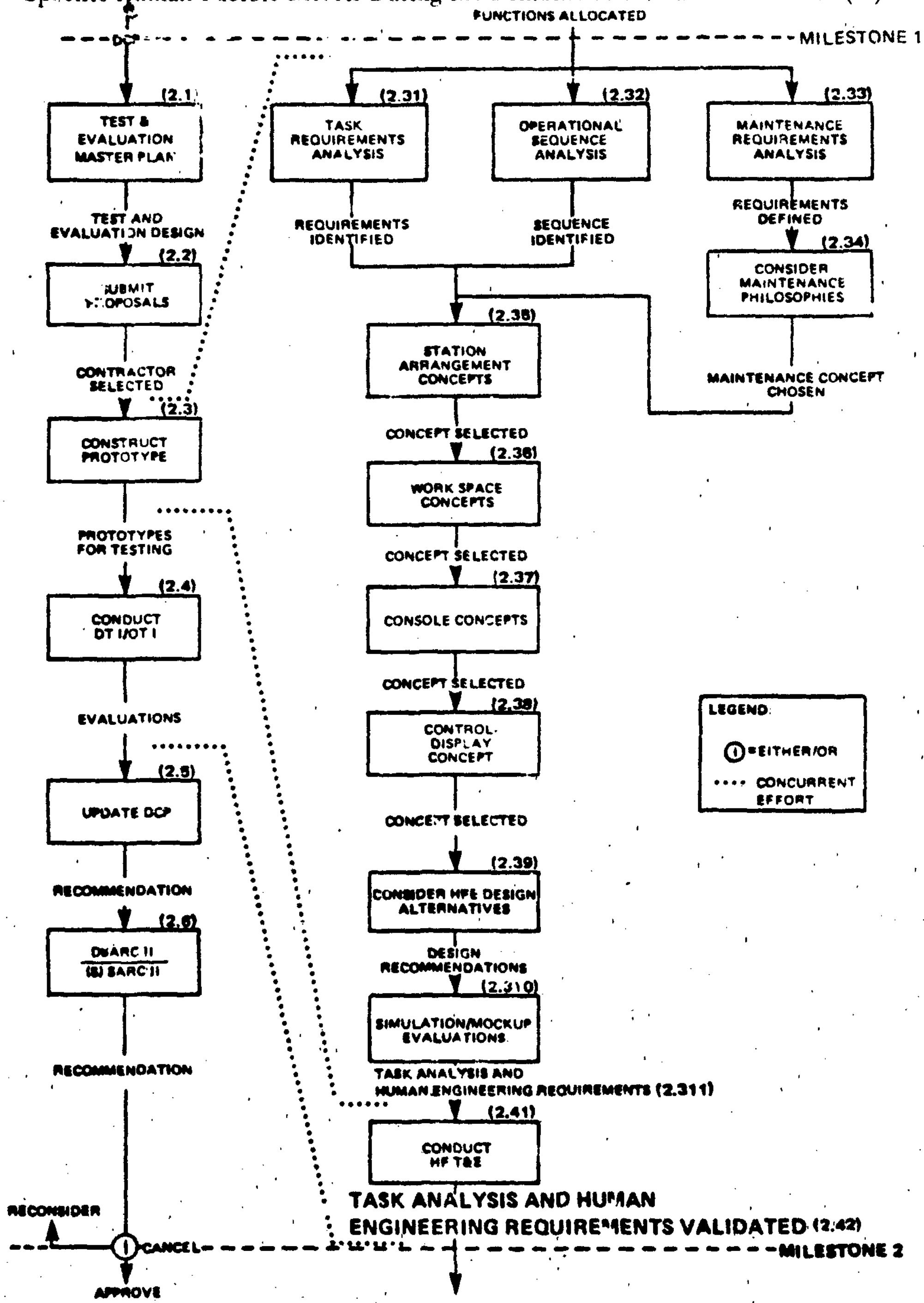
This subsection provides a description of the human factors efforts and system development activities shown in Exhibit 3-8. The descriptions are keyed to the numeric codes on the chart. The product of the Concept Development Phase should be input directly to human factors activities requisite to the Demonstration/Validation Phase. The product of this phase contains two components overall which distinguish two elements: (1) Task Analysis, and (2) Human Engineering Requirements. The results of the former serve as major input to the latter developments.

(2.1) Test and Evaluation Master Plan (TEMP). The TEMP is the controlling document which derives test and evaluation requirements for development test and evaluation and operational test and evaluation. The TEMP identifies decision criteria and funding constraints in support of the overall approved program objectives.
(Adapted from OPNAVINST 5000.42A and SECNAVINST 5000.1A)

(2.2) Submit Proposals. Since development of a prototype system is a major requirement of the Demonstration and Validation Phase, a request for proposal (RFP) must be prepared, contractor proposals written and submitted, and a winning contractor(s) awarded the contract to develop the prototype. Requirements to be issued in the RFP should be obtained from the TEMP, the DCP of the previous phase, and previous activities' results.

Exhibit 3-8

Specific Human Factors Efforts During the Demonstration/Validation Phase (2.)



(2.3) Construct Prototype. The purpose of a prototyping effort in the Demonstration/Validation Phase is to confirm that the technology is feasible and that the design concept has military utility against a stated military requirement. Prototypes may also be fabricated for competitive evaluation to select the best approach for further development. Human factors activities relevant to the Demonstration/Validation Phase should be conducted in association with the development of the prototype. (Adapted from AR 70-1)

(2.31) Task Requirements Analysis. Requirements for human performance are generally gained through the development of a task analysis for a specific system in mind. Most task analysis requirements are derived through a two-step process involving: (1) subtask derivation and (2) skill and knowledge analysis. Subtask derivation results in task descriptions, work designation (operator/maintainer/support), task locus, and behavior and time/sequence variables. Task skill and knowledge analysis results in assignment of skill level to tasks/subtasks, military specialty requirements, and necessary and/or special knowledge requirements. (Adapted from VanCott & Kinkade, 1972)

(2.32) Operational Sequence Analysis. Dynamic analysis of the operations environment, such as that offered by operational sequence diagramming (as opposed to static analysis such as that offered by task analysis), provides time-based data revealing among other things operator workload requirements, performance requirements exceeding operator and equipment capabilities, and sequences amenable to translation into training and mission scenario development.

(2.33) Maintenance Requirements Analysis. A maintenance task equipment requirements analysis is conducted to define

requisite maintenance tasks, test equipment utilized and procedures for their use, equipment to be maintained, and malfunctions possible. This data is used to determine skill level and knowledge requirements for maintainers of system components, and training requirements for maintenance (including criteria and measures of performance). In addition, maintenance support should be considered for inputs on maintenance of system effectiveness.

(2.34) Consider Maintenance Philosophies. Having obtained detailed requirements for system maintenance, consideration should be given to the choice of maintenance philosophies to be implemented. These especially involve the input of human factors to agencies responsible for training and support of maintainers. Recommendations for training requirements, training devices and simulation requirements, and job aids and manuals should also be developed.

The previous discussion constitutes what is roughly equivalent to the determination of requirements for human performance through human task analysis. This data (along with data prepared in previous stages of system development) should be utilized in the specification of human factors engineering requirements. These requirements are then used to support development of the prototype system. The ensuing discussion details the general plan for this process.

(2.35) Station Arrangement Concepts. Proceeding from a general level of detail, a preliminary arrangement of personnel and equipment within the workstation is made. This process is generally based on knowledge of information flow within the station (as determined by such a technique as information flow charting) as well as knowledge of communication and operator traffic flows (as determined in link analysis, for example).

(2.36) Workspace Concepts. While the station arrangement process described above is concerned with interactive performance of men and machines, workspace concepts deal with environmental and other associated aspects of the station and other locations, involving even men in passive states with respect to the system. Environmental effects deal with issues of climate and habitability. Safety, personnel mobility, equipment space, and other associated requirements must be considered in relation to workspace conditions.

(2.37) Console Concepts. The above considerations dealt with crews and/or nonspecific individual operator requirements. Console concepts, on the other hand, involve primarily a specific operator in relation to specific duties and equipment/components. Considerations that require examination for design implications of individual operator consoles include operator visual, auditory, manipulatory, and ambulatory requirements. Different standards are applied to console concept selection involving stand-up and sit-down operators.

(2.38) Control-Display Concepts. The final analysis in relation to development of personnel work stations is the specification of control-display concepts. This paper-and-pencil arrangement analysis of controls and displays on panels and consoles should be based on an analysis of operator utilization frequency, accuracy, sequence, etc. and the importance of these displays and controls to controlling or monitoring system performance. Guidelines for these purposes include general topics such as the following:

1. Priorities for locating controls and displays
2. Spacing between controls and displays
3. Grouping controls and displays to either function or sequence
4. Sequence of operation.

(Adapted from MIL-HDBK-759)

The preceding discussion is clearly slanted toward the operations side of a system. Analysis of the maintenance portion must also proceed through a process similar for operations. Concepts to be included in this sort of maintenance analysis must focus upon aspects of equipment and test equipment portability, equipment and workspace accessibility, and procedures associated with maintenance actions (e.g., fault isolation, correction, and prevention).

(2.39) Consider Human Factors Engineering (HFE) Design Alternatives. The concepts derived above must now be grouped together to evolve alternative requirements for human factors design wherever there is a man-machine interface. Analysis at this stage must reconcile potential crew interaction problems and individual workload capabilities and limitations. Each alternative, as well as the one selected as optimal, should be presented in the form of drawings, tabulations, and narratives.

(2.310) Simulation/Mockup Evaluations. To begin verification of analyses performed up to this point, as well as to begin HFE detail design based on actual studies of the man-machine interface, the use of simulation, mockups, and their subsequent evaluation must be performed. These activities should result in determining the efficacy of the HFE design alternative recommended, as opposed to the remaining alternatives. In addition, development and refinement of specific HFE design parameters should also proceed to the extent of confirming the validity of HFE design alternatives--this can be done to the level of drawings, tabulations, and narratives, or through providing data pertinent to their modification.

(2.311) Human Performance and Human Engineering Requirements. As stated previously, the major HFE product of the Demonstration/Validation Phase is the specification of human task analysis and

human factors engineering requirements. Since it is a major product, it has been previously introduced as such and will not be repeated here.

(2.4) Conduct DT I/OT I. Primary verification of the feasibility of a prototype system to achieve stated requirements is determined through development test (DT) and operational test (OT). In the Demonstration/Validation Phase these are DT I/OT I.

> DT I is conducted to demonstrate that technical risks have been identified and that solutions are in hand. Components, subsystems, brassboard configuration or advanced development prototypes are examined to evaluate the potential application of technology and related design approaches prior to entry into full scale development.
> (DA Pam 11-25)

OT I is conducted to determine military validity and worth to the user. OT I estimates:

a. The potential of the new system in relocation to existing capabilities

b. The relative merits of available competing prototypes/ systems from the aspects of military utility

c. The adequacy of the concepts for employment, support ability organization, doctrinal, tactical, and training requirements, and related critical issues.

(Adapted from DA Pam 11-25)

(2.41) Conduct Human Factors T&E. Human factors test and evaluation (HF T&E) is conducted in conjunction with OT I. The purpose of HF T&E for the overall system development is to demonstrate that human performance technical risks have been identified along with their solutions. HF T&E also attempts to validate the human task analysis and the human factors engineering requirements.

(2.4) Task Analysis and Human Factors Engineering Requirements Validated. The development of validated task analysis and human factors engineering requirements will provide the next phase of development with valid human factors data to firm up the detail design wherever a man-machine interface is located.

(2.5) Update DCP. The Decision Coordinating Paper (DCP) is updated to include recommendations for further system development as well as designation of preferred alternative designs and rationales for such choices.

(2.6) DSARC II/(S)SARC II. The purpose of DSARC II/(S)SARC II is to evaluate the readiness of the system development program to enter full-scale development. Reviews are conducted of the DCP, among other documents. Approval by the DSARC and (S)SARC sets the stage for continued development of the system.

<u>Content of the Task Analysis and Human Engineering Requirements Product</u>

A documented task analysis and statement of the system human engineering requirements shall include the following considerations:

<u>Assumptions:</u>

The following items will serve as input to the process of determining human performance and human factors engineering requirements:

- MENS
- DCP
- Products of function allocation.

Task analytic techniques will be utilized to encompass pertinent aspects of operations and maintenance for a proposed system. Requirements for human factors engineering will also encompass operations and maintenance.

Actions:

1. The principal product of the human task analysis portion of this phase will be a completed task analytic package (including static and dynamic aspects for all tasks). Overall, the package will provide the following data:

   a. tasks and task sequences required of operators and maintainers

   b. actual equipment employed

   c. safety

   d. maintenance.

   Techniques utilized to derive these data will include procedures such as the following: Behavioral Task Analysis, Operability/Maintainability Analysis, Hazard Analysis, Workload Analysis, Task-Equipment Analysis, Operational Sequence Diagrams, and Link Analysis.

2. The overall task analysis, including task descriptions, will be presented in the form of flow diagrams, tabular presentations, and narratives.

3. The human task analysis will commence with a summary of gross tasks. This summary will demonstrate the feasibility of achieving system performance requirements as well as ensuring that human performance requirements do not exceed capabilities. In addition, the effects upon the following items will be described:

   a. manning level

   b. equipment procedures

   c. requisite skills and training

   d. communication requirements (between operators and operators and the system)

   e. logistics support.

4. The human task analysis will specify tasks critical to system performance as well as evidence to support its criticality. These tasks will include but not be limited to the following data:

   a. information requirements by operators/maintainers (including cues for task initiation)

   b. information available to operators/maintainers

   c. evaluation process

   d. decisions reached after evaluation

   e. action taken

   f. body movement required by action taken

   g. workspace envelope required by action taken

   h. workspace available

   i. location and condition of work environment

   j. frequency and tolerance of action

   k. time base

   l. feedback, informing operators/maintainers of the adequacy of action taken

   m. tools and equipment required

   n. number of personnel, specialties, and experience

   o. job aids or references

   p. communication required (including type)

   q. hazards

   r. interaction of multiple personnel

   s. operational limits of personnel (performance)

   t. operational limits of machine and software.

5. The human task analysis package will provide the results of an operability/maintainability workload analysis (including the interaction of multiple personnel). The operability analysis will detail the following:

   a. design goal--quantity and quality of information throughput

   b. predict expected quantity and quality of throughput operators should expect

   c. comparison of predicted with desired throughput and resolution of differences.

   The maintainability analysis will detail the following:

   a. design goal--~~including the~~ effects of automated maintenance

   b. predict performance times for correction (including identification, fault isolation, and correction) of system malfunctions

   c. compare predicted maintenance with goal and resolve differences.

6. Develop requirements for human factors engineering by analysis of effects of critical tasks upon system and equipment performance, cost, periods of peak personnel workload, conflict situations placing demands upon personnel and equipment as well as requirements not previously apparent. In addition, life support characteristics will be detailed covering but not limited to the following: noise, shock and vibration, temperature extremes, atmospheric contamination, toxicity, electric shock, mechanical hazards, electromagnetic and nuclear radiation, explosion/fire, pressure and/or decompression.

This analysis will also result in the prediction of the probabilities for operator and maintainer error. Details to be included in the error analysis are:

a. identification of the locus of errors

b. malfunction

c. extreme conditions and environments

d. effects of enemy action

e. recommendations for avoidance of design-induced error

f. rating of error likelihood

g. rating of error criticality

h. estimate of seriousness of consequences to personnel and/or equipment; and system, subsystem, and/or component performance.

7. Additional requirements for human factors engineering involved with development of procedural documents, personnel planning, and system testing will be developed. This data will be obtained from an analysis resulting from the compilation of task-related data into preliminary operator/maintainer procedurally oriented task descriptions. (Especially important in this regard would be the determination of system and personnel performance time and accuracy requirements to be used in system test and evaluation. A sequential analysis of the operational sequence diagram would provide these data on a dynamic basis suitable for this use.)

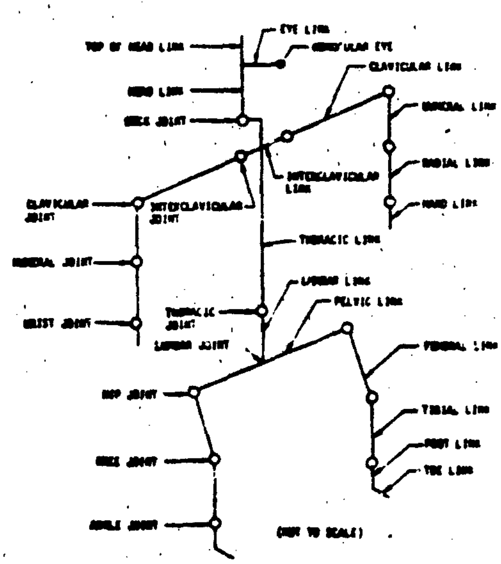
Demonstration/Validation Phase:
Example of Human Factors
Contribution

The crewstations of an aircraft must be usable by crewmembers who vary widely in physical size. If a significant number of pilots cannot reach the critical controls, accidents and injuries will increase. Between 15 and 20 aircraft mishaps per year have been attributed to difficulties in reach, at a cost of 20-30 million dollars in damage. The problem has become serious enough that the Chief of Naval Operations recently asked that aviators be matched with specific aircraft according to how well they "fit" the physical dimensions of the cockpits and controls. While this approach is effective in reducing accidents, it limits the use of the trained aircrew population and wastes valuable training and retraining time. Pilot/cockpit size mismatches can usually be solved by early engineering design changes. But to do so requires that cockpit geometry mismatches be detected while the aircraft is still on the drawing board. To that end, the Navy needs a method of analysis that can compare and quantify planned cockpit geometry against the aircrew population at this early design stage.

To meet the need for a method of comparison, NADC developed the Crewstation Assessment of Reach (CAR) model. The CAR model is based on extensive prior research in industry and government. This work has resulted in sophisticated cockpit geometry models which can compare the physical dimensions of a specific operator against the dimensions of a proposed crewstation. The CAR model uses a condensed version of those earlier models to evaluate a cockpit design against a statistical sample representing the entire operator population. Thus, CAR is able to estimate the percentage of available aircrewmen who can operate a proposed design and the percentage who will have difficulty in performing any specific control action.

CAR is applied at the earliest possible stage of design, using the initial drawings as an input. The model examines hand and leg control positions, head/canopy clearance, and seat movement required to achieve over-the-nose vision. Where reach or clearance problems are detected, CAR identifies the controls involved. Because the computer program is "interactive," the researchers can immediately evaluate alternative designs. A large number of alternatives can be explored with a minimum of time and cost, and acceptable solutions can be identified promptly.

CAR uses a mathematical model of the human skeleton, consisting of the major body segments ("links") and the joints which connect those links, with all their lengths, limits of movement, and variations in dimension within the operator population (see figure). It can quickly calculate how the skeletal model must move to perform any specific action, under various conditions of harness restraint or requirements for hand action (e.g., grasp, touch, manipulate).



CAR Body-Model

CAR has been used in the design of three aircraft: the Light Airborne Multi-Purpose System (LAMPS) MK-III (SH-3), the F-18, and the AV-8B. For LAMPS and the F-18, changes were recommended and were used in further development. For the AV-8B, studies are still in progress to correct some identified problems.

Applied to the F-18 preliminary design, CAR revealed that only 10% of the aviator population would be able to use all critical controls. The seat, stick, and emergency controls were therefore relocated, using CAR recommendations, to accommodate nearly 100% of aviators. The engineering changes that were required included major modifications of the aircraft structure.

CAR has been adopted for use elsewhere in the government and in industry. Within the government, it has been modified by NASA for Space Shuttle design. In industry, it has been used in-house by McDonnell Douglas, Northrup, Sikorsky, the Clark Equipment Company, and IBM.

Earlier methods of analyzing cockpit geometry required laborious manual procedures, or else computer models not suitable for use in early stages of design. The results were often expensive, late, imprecise, and hard to convey to design engineers. At worst, problems remained undetected until the aircraft were in service, and then often surfaced as accident data. CAR improves the accuracy of analysis while reducing the time required from more than two weeks to less than a day, with a 90% decrease in cost. CAR can be applied earlier in the design cycle than ever before, and used interactively to find engineering answers and test them ahead of time. It will produce aircraft which are more mission-effective because they are better fitted to the aircrew.

For example, when used to guide design of the F-18, CAR made it possible to correct on paper design deficiencies that would have cost millions to change if not detected until construction began. Savings through avoiding lost training time for pilots who could not have safely used the initial design are estimated at 10 to 40 million dollars per year.

Full-Scale Development Phase Human Factors

This phase should result in a firm and detailed man-machine interface design. At the start of the phase, various man-machine combinations should be considered that would satisfy the human performance and human factors engineering requirements. The testing of these combinations by simulation or mockups should identify the most effective combinations. Simulation trials are a good method for pinpointing peak personnel and equipment workloads, detecting probable human errors, identifying inefficient interfaces, and determining if the design is appropriate for the intended user.

The equipment must be designed to meet the physical and cognitive needs of the intended user. Physically, the equipment must be designed to permit effective movement, effective use of knobs and controls, transporting of goods, effective use of arms and legs, or whatever the tasks call for. Cognitively, the human factors engineer is responsible for recommending designs that are neither too difficult nor simplistic, but that, rather, assign the proper amount of cognitive workload to different kinds of users. To have an effective system, the design must differ for different types of users. One design would be appropriate if a position is expected to have high turnover in short periods of time and the user is to be minimally trained and to possess few skills, while another design would be appropriate for a position with less turnover and occupied by a user with better training, skills, knowledge, and ability to make complex decisions.

The man-machine tests and evaluations should cover every detail of the design, from such things as effectiveness of a type of information displayed at various times to control-display compatibility, spacing of controls, shape of controls, sequence of controls, anthropometry, and in general, all of those areas in MIL-STD-1472B and MIL-H-46855B. The HF T&E in this phase should result in a reliable man-machine design.

Human Factors Efforts and System Development Activities During Full-Scale Development

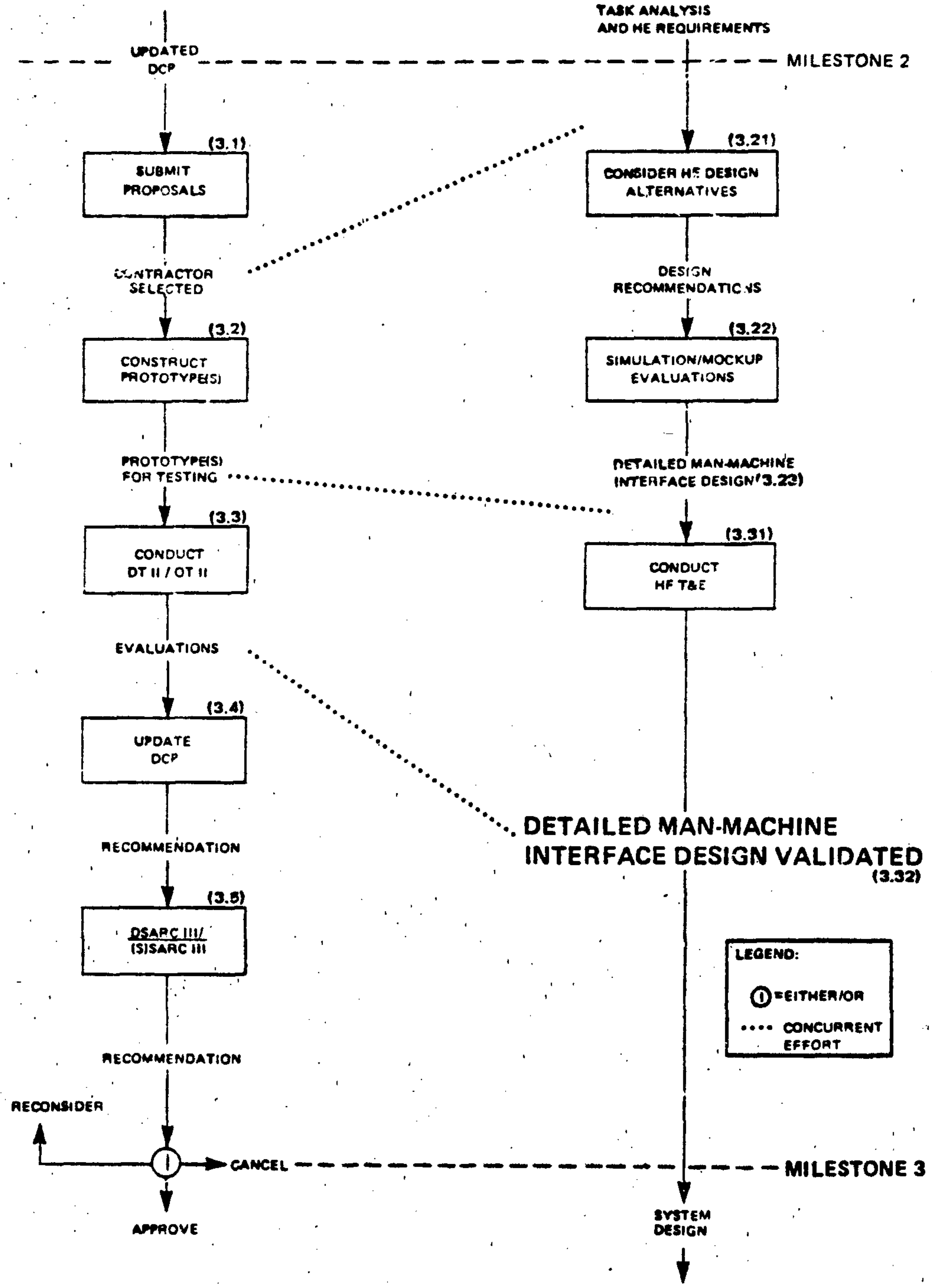
The major human factors products of the Demonstration/ Validation Phase, task analysis, and human engineering requirements serve as the basic data for the detailed human factors design of the system wherever a man-machine interface occurs. This subsection provides a description of the human factors efforts and system development activities shown in Exhibit 3-9. The descriptions are keyed to the numeric codes on the chart.

(3.1) Submit Proposals. It is possible that in full-scale development a different contractor may be selected than the contractor employed in the Demonstration and Validation Phase. In addition, it is also possible (albeit unlikely) to continue with competitive developments. For these reasons (although they are somewhat rare in occurrence) the complete cycle involving RFPs, proposals, and contract award is repeated.

3.2 Construct Prototype(s). When development prototypes are fabricated in full-scale development, the intent is to assure that the engineering problems have been solved and to permit thorough evaluation of the system. (This occurs prior to a commitment to full-scale production or simultaneously with low-rate initial production.)
(AR 70-1)

Exhibit 3-9

Specific Human Factors Efforts During the Full-Scale Development Phase (3.)



It has traditionally been during this stage of development (prototyping in full-scale development) that the bulk of human factors R&D has occurred.

(3.21) Consider HFE Design Alternatives. Before entering full-scale development, a decision is required whether to accept or modify the prototype system built and tested previously in the Demonstration/Validation Phase. For HFE proper, this encompasses the man-machine interface. This is necessary when any or all of the following events occur:

1. Contractor awarded full-scale development is different from contractor during Demonstration/Validation Phase.
2. Deficiencies identified through the HFE portion of OT I require modification to the system (this may also include DT I/OT I findings at large as well).
3. Design requirements change development of hardware and software components (e.g., to take advantage of newly breaking technologies), thus forcing HFE to keep abreast of development.

Based on events occurring as illustrated above, HFE will provide design recommendations.

(3.22) Simulation/Mockup Evaluations. Should hardware and/or software design requirements be modified resulting in changes to the man-machine interface, new studies and analyses involving simulation and/or mockups may become necessary to evaluate the effects of change upon personnel (operators/maintainers) workload, and assigned activities. Analysis may be required especially when the effects of design changes are unknown.

(3.23) Detailed Man-Machine Interface Design. Final HFE design requirements should be prepared in the following formats:

drawings, tabulations, and narratives. This will facilitate their implementation in detail design of the full-scale development prototype. HFE requirements include human engineering principles and criteria which offer assurance that the final product can be efficiently, reliably, and safely operated and maintained. Relevant locations for the application and human factors engineering include the work environment, crewstation, and facilities being designed for the system.
(Portions from MIL-H-46855)

The product of this phase is the design of an optimal man-machine interface. It is discussed elsewhere and will not be repeated here.

(3.3) Conduct DT II/OT II. Developmental Test II and Operational Test II (DT II/OT II) are required to determine whether or not the full-scale development prototype is ready for production.

DT II ensures that engineering is reasonably complete, that all significant design problems have been identified, and that solutions are in hand.

OT II provides a valid estimate of expected system operational effectiveness and suitability as determined through tests involving the aid of operational and support personnel of the type and qualifications of those who are expected to use and maintain the system when deployed.
(Adapted from AR 70-10)

(3.31) Conduct HF T&E. Conjointly with OT II, Human Factors Test and Evaluation of the full-scale development system will be conducted to:

1. Assure fulfillment of the applicable requirements

2. Demonstrate conformance to HFE design criteria

3. Determine whether undesirable design or procedural features have been introduced.

(Adapted from MIL-H-46855)

(3.32) Detailed Man-Machine Interface Design Validated. The results of an HF T&E should be validation and verification of design requirements to provide an optimal man-machine interface design.

(3.4) Update DCP. The Decision Coordinating Paper is updated to include a current evaluation of the system. The decision to proceed into full production must be based on this DCP.

(3.5) DSARC III/(S)SARC III. Defense System Acquisition Review Council III/(Service) System Acquisition Review Council III purposes are to recommend to the Secretary of Defense approval of production (or, possibly, low-rate initial production) of a system. The DCP, among other documents, is reviewed during this process.
(DA Pam 11-25)

Content of the Optimal Man-Machine Interface Design

The optimal man-machine interface design recommendations should include the following considerations:

Assumptions:

The following items will be regarded as inputs to the human factors engineering design of the man-machine interface:

- Design criteria documents (e.g., MIL-STD-1472)
- Performance specifications
- Drawings and data (e.g., functional flow diagrams, schematic block diagrams, interface control drawings, overall layout drawings)
- Human factors engineering input (e.g., task analysis) converted to detail equipment design features.

The following processes are considered characteristic of this phase of system development:

- Human factors engineering studies, experiments, and laboratory tests (to resolve human factors and life support issues)
- Mockups and models
- Dynamic simulation (necessary for detail design of equipment requiring critical human performance)
- Human factors engineering contributions to detail design
- Human factors engineering contributions to manpower, personnel, and training issues as a consequence of detail design
- Human factors contributions to test and evaluation.

Actions:

1. Effects of the working environment, including habitability and operability, will be presented. These effects will cover the following areas: work environment, crew stations, and facilities. The incorporation of human factors into the detail design of the above will be demonstrated by presenting detail design drawings, specifications, etc. for the following three conditions: normal, unusual, emergency.

Topics to receive coverage will include at least the following:

a. atmospheric conditions

b. weather and climate

c. range of accelerative forces

d. acoustic noise, shock, and vibration

e. disorientation

f. accessibility

g. adequate visual, auditory, and physical links

h. adequate non-workspace areas

i. psychophysical stress

j. fatigue

k. clothing and personal equipment

l. equipment handling

m. chemical, biological, electrical, electromagnetic, toxicological, and radiological effects

n. illumination

o. sustenance, storage, and refuse

p. safety protection.

2. The incorporation of human factors in detail design of the crewstation layout/arrangement and of equipment having an operator/maintainer interface will be demonstrated. This will include the presentation of drawings illustrating the inclusion of human factors; for example: panel layout drawings, communication system drawings, overall layout drawings, and control drawings. The following additional items will be requisite to the demonstration of the inclusion of human factors in system detail design:

a. ingress and egress to workspace and facilities

b. a list of panels, racks, controls, displays, and indicators existing at the time of documentation which have received human factors approval

c. rationale of human factors layout/arrangement, detail design of crew station(s), and any equipment having an operator/maintainer interface

d. a list of considerations used to arrive at design decisions: results of studies, requirements based on task analysis, mock-up tests, mock-up based decisions, and simulations

e. a list and explanation for deviations from human factors or design requirements to the man-machine interface

f. sketches, drawings, and photographs of required or anticipated panel and rack arrangements or new designs/design modifications

g. drawings or photographs of each crewstation design showing locations of all crewstation panels in relation to seat/operator position.

3. **The inclusion of human factors in design considerations involving the interaction of maintenance technicians with their respective equipment will be demonstrated. In general, this will depict the following steps/stages:**

a. recognition of malfunctions (displays)

b. isolation of malfunctions (troubleshooting)

c. fault correction (access, removal and replacement, repair).

A human factors maintainability/accessibility design analysis will be presented to include at least the following:

a. preliminary drawings, sketches, or photographs showing each equipment and location in relation to surrounding equipment, passageways, and structures (this includes ancillary equipment also)

b. rationale of human factors design of each item requiring maintenance as well as presentation of decisions used to drive the decision process (e.g., MIL-STD-1472, results of studies, simulation, mockups)

c. incorporation of maintenance task analysis

d. descriptions to include but not be limited to the following:

   - physical size, purpose of support, and test equipment required for maintenance
   - maintenance procedures
   - relation between accessibility and failure rate, service frequency, calibration frequency, and requirements for rapid maintenance
   - methods used to determine accessibility for maintenance
   - anticipated maintenance and accessibility problem areas.

4. Best available data on equipment operating procedures, operational sequence diagrams, and task analysis will be provided to organizations responsible for manpower development.

5. A human factors test and evaluation plan will be prepared to cover the following general concepts:

   a. fulfillment of human factors requirements

   b. conformance to human factors design criteria

   c. quantitative measures of system performance

   d. detection of undesirable design or procedural features.

Full-Scale Development Phase: Two Examples of Human Factors Contributions

The example that follows is actually a case of system modification rather than system development, but the human factors impact is conceptually the same.

The Strategic Air Command (SAC) is continually considering proposed new hardware or modifications to existing hardware for improving offensive and defensive avionics equipment in the B-52 fleet. These new subsystems are expensive and must be evaluated with respect to the degree of additional combat crew effectiveness that can be realized. In short, the new equipment must be operable in the B-52 mission environment by the current population of electronic warfare officers and must result in improved mission performance.

The Strategic Avionics Crew Station Design Evaluation Facility (SACDEF), developed by the Human Engineering Division at Wright-Patterson Air Force Base, is on-line to provide the effective selection of offensive and defensive avionics equipment and integration for B-52 improvements. This capability involves the quantification of Strategic Air Command crewmember actions in conducting simulated Single Integrated Operations Plan (SIOP)

missions. It uses computer-integrated electronic warfare and bombing/navigation systems simulators to evaluate performance improvements obtained by means of proposed new equipments and crew station reconfigurations.

Trained crewmembers' performance is monitored and statistical analyses of combat crew performance with the proposed hardware are provided to SAC. Recommendations made by the human factors specialists have been well received (87 of 93 original recommendations were adopted in the Phase VI update of the B-52 fleet). Further, the Strategic Air Command has adopted the policy that no new hardware will be installed on the B-52 fleet until their trained crewmembers have participated in the evaluation studies conducted at Wright-Patterson AFB. The results of this capability are not only used directly by the using command, but also provide technology advances in systems effectiveness modeling and simulation that will enhance man-machine integration "try-before-buy" evaluation of new weapon systems.

The Aerospace Medical Research Laboratory is now developing a comparable test and evaluation capability for navigator/radar navigator functions in conjunction with the proposed update of the B-52 avionics systems in support of SAC ROC 75-6.

A final example follows which fully illustrates the impact of human factors R&D upon design and development of military systems in the Full-Scale Development Phase (Gartner et al., 1958).

Good human engineering of equipment controls and displays has long been a hallmark of human factors R&D. This is due to the fact that well human engineered equipment design can have a dramatic effect upon the operability of systems. Rarely, though,

has there been an opportunity to compare a "pre-human engineered" design of an item of equipment with a human engineered version in order to substantiate claims as to the value of this particular human factors technology. One such opportunity did arise, however, when an empirical experimental investigation between two alternative designs of test equipment for complex naval mines was performed. This project, which involved development of design recommendations, detail design, fabrication, experimental investigation, and evaluation of test equipment items, was embedded within a larger program to offer human engineering support to test equipment designs as well as development of a human engineering design guidebook for engineers.

As outlined above, the following approach was taken: Two test equipment items were fabricated according to human engineering recommendations and the same two items were fabricated according to their original designs. The original design test equipment and the human engineered test equipment were then empirically compared against each other with respect to criteria of time and error. Results indicated that successful improvements in performance (i.e., use) of the human engineered test equipment occurred with regard to reductions both in time to task completion and reduced error likelihood. With practice, performance on both test equipment designs converged. However, since it was known that utilization of the test equipment was to be too infrequent for users to sustain learning, the human engineered version was considered necessary. Furthermore, it was also felt that practice effects would operate for either design version, with the expectation of greater influence on operators using the human engineered equipment.

This research demonstrates the value of human factors R&D in Navy mine test set design. Implementation of human factors design recommendations (such as were developed for the test set

equipment and documented in a guidebook for test equipment development and design) in a systematic and standardized manner could lead to greater user performance differences between the human engineered and non-human engineered designs. This may be due to overall familiarity with characteristic arrangements of controls and displays. Standardization procedures in human engineering design which utilize known population stereotypes with regard to user expectations could result in dramatic reductions in time to task completion and human error. These goals are crucial to design of an optimal man-machine interface.

Production and Deployment Phase Human Factors

If human factors have been properly thought out and executed, the system should be ready for production and deployment after Milestone 3. However, there are provisions for additional engineering and human factors testing (DT/OT III) if the tests and evaluations in DT/OT II indicate problems. The additional testing is conducted on the first few systems in the initial low-rate production. When additional testing indicates the problems have been corrected, the system goes into full-scale production.

If any problems arise or if improvements seem prudent after the system is fielded, the system acquisition model provides for additional testing to recommend design changes. A good human factors plan will keep these costly design changes to a minimum.

The scope of the present project is strictly with the system development phases of the acquisition process and is not concerned with production and deployment. However, to provide some closure to the process, a brief description of production and deployment follows. No human factors products are defined, and no examples are included.

Human Factors Efforts and System Development Activities During Production and Deployment

This subsection provides brief descriptions of the general human factors efforts and system production and deployment activities shown in Exhibit 3-10. The descriptions are keyed to the numeric codes on the chart.

(4.1) Initial Production. When it is decided to enter production of a system, initial production items are generally used for production tests and follow-on evaluations as necessary. Generally, production is not suppressed to await completion of follow-on evaluation (nor for that matter does deployment await conclusion of this evaluation).
(Adapted from AR 1000-1)

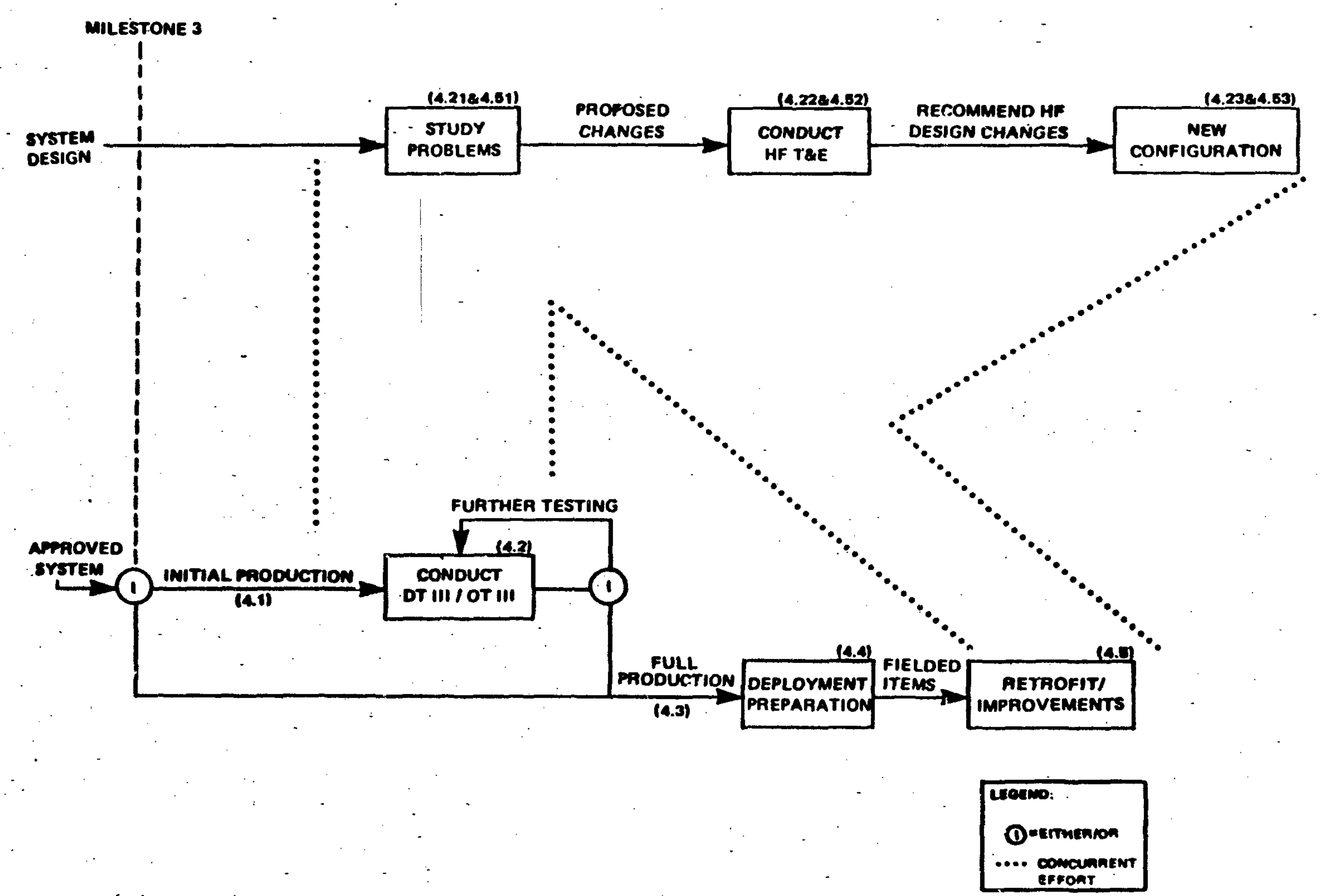
(4.2) Conduct DT III/OT III. Development Test III/ Operational Test III are conducted to determine if production units have the capabilities demonstrated in prototypes and are operationally suitable and effective.

DT III is conducted on production prototypes or production items delivered from either an initial or a pilot production run. The purpose is to verify their adequacy and quality when they are produced in quantity and according to production contract specifications, using quantity production processes. This test determines whether or not the transition from an engineering development prototype to a production item has been made successfully.

OT III is normally a test of initial production and has the fundamental purpose of providing data on the item or system in order to estimate its operational suitability, verifying that all testable critical issues have been resolved, and determining that all benefits and burdens of the item or system are identified.
(Adapted from AR 70-10)

Exhibit 3-10

Specific Human Factors Efforts During Production and Deployment (4.)



Additional testing is implemented where required to resolve (hopefully) residual problems.

(4.21) Study Problems. Any HFE problems identified following Milestone 3 are studied to determine means to alleviate them. In considering redesign, an analysis of the loss of production time, increased costs due to redesign effort, and production costs must be made in order to realistically determine what human factors alternatives are feasible. Often, consideration is given to increased training and/or personnel with higher skill levels than was previously decided.

(4.22) Conduct HF T&E. Additional human factors test and evaluation (HF T&E) may be ecessary to (1) determine the efficacy of the proposed change (2) determine how well a specific change has improved operation/maintenance of the system.

(4.23) New Configuration. A new man-machine interface is configured as a result of human factors design changes. Personnel and training requirements as well as system operability are often affected as a result of such changes, and may necessitate further investigation.

(4.3) Full Production. Full-scale production will proceed following approval based on findings of DT III/OT III.

(4.4) Deployment Preparation. Deployment of systems to the field includes not only delivery and set-up of the new system. It also requires fulfillment of requirements found in an initial operational capability, such as: user unit is equipped with production items that are deemed suitable, with unit personnel that are adequately trained to operate, care for, and maintain the item, and the unit has the capability to perform its assigned mission.
(Adapted from TRADOC Reg. 600-4)

(4.5) Retrofit/Improvements. Based on problems identified in actual use, or change in doctrine, threat or mission product improvements and/or retrofit programs may be needed to resolve them. This also requires the cognizance of, and often the analysis by, HFE personnel to ensure that personnel and training requirements are covered as well as that system man-machine interface optimization is maintained.

(4.51) Study Problems. See 4.21.

(4.52) Conduct HF T&E. See 4.22.

(4.53) New Configuration. See 4.23.

References

Baker, C.C., Johnson, J.H., Malone, M.T., & Malone, T.B. Human factors engineering for Navy weapon system acquisition. Naval Sea Systems Command, Washington, D.C., July 1979.

Coburn, R. Human engineering guide to ship system development: Responsibilities, procedures, and methods for carrying out human engineering programs. NELC/TD 278. San Diego, CA: Naval Electronics Laboratory Center, October 1973.

Collins, J.J., McGuinness, J., Erlichman, J., & Boyce, S. Human factors engineering integrated technology in total ship planning and acquisition: A first approximation. Prepared under Contract N0024-75-C-6139 for Naval Sea Systems Command, Washington, D.C., August 1975.

Department of the Air Force. Human factors engineering and management. AFR 800-15. October 1974.

Department of the Army. Army research, development, and acquisition. AR 70-1. 1 February 1977.

Department of the Army. Test and evaluation during development and acquisition of materiel. AR 70-10. 29 August 1975.

Department of the Army. Threat analysis. AR 381-11. 1 October 1974.

Department of the Army. Human factors engineering program. AR 602-1. June 1976.

Department of the Army. Basic policies for systems acquisition. AR 1000-1. 1 April 1978.

Department of the Army. Life cycle system management model for Army systems. DA Pam 11-25. May 1975.

Department of Defense. Major systems acquisitions. DOD Directive 5000.1. January 1977.

Department of Defense. Major system acquisition process. DOD Directive 5000.2. January 1977.

Department of Defense. Test and evaluation. DOD Directive 5000.3. April 1978.

Department of Defense. Major system acquisition. DOD Directive 5000.1. March 1980.

Department of Defense. Major system acquisition procedures. DOD Instruction 5000.2. March 1980.

Department of Defense. Test and evaluation. DOD Directive 5000.3. December 1979.

Department of the Navy. Human factors. NAVMATINST 3900.9. Naval Material Command, Washington, D.C., September 1970.

Erikson, R., Miles, J., & Secrist, G. Technology Coordination Paper: Training and personnel technology. Department of Defense, August 1978.

Gartner, W.B., Price, H.E., et al. An experimental evaluation of the application of human engineering principles to mine test set design. PRA Report 58-2. Bureau of Ordnance, Department of the Navy, January 1958.

Geddie, J.C. Human factors model. Personnel communication, HEL, Aberdeen, MD, November 1979.

Goclowski, J.C., King, G.F., Ronco, P.G., & Askren, W.B. Integration of human resource technologies in weapon system design: Process for the coordinated application of five human resource technologies. AFHRL-TR-78-6(II). Wright-Patterson AFB, OH: Air Force Human Resources Laboratory, March 1978.

Human engineering design criteria for military systems, equipment, and facilities. Military Specification MIL-STD-1472B, May 1978.

Human engineering requirements for military systems, equipment, and facilities. Military Specification MIL-H-46855B, 1979.

Kaplan, J.D., & Crooks, W.H. A concept for developing human performance specifications. TM-7-80. Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory, April 1980.

Meister, D., & Rabideau, G.F. *Human factors evaluation in system development*. New York: John Wiley & Sons, 1965.

Merriman, S.C. Human factors programs in Navy systems acquisition. PMC 76-2. Defense Systems Management College, Ft. Belvoir, VA, November 1976.

MIL-HDBK-759. Military standardization handbook: Human factors engineering design for Army materiel. Aberdeen Proving Ground, MD: U.S. Army Human Engineering Laboratory, March 1975.

MIL-STD-490. Specification practices. Department of Defense, 30 October 1968.

Office of Management and Budget. Major system acquisitions. Circular No. A-109. Executive Office of the President (OMB), Washington, D.C., April 1976.

OPNAVINST 5000.42A. Weapon system selection and planning. Department of the Navy, 3 March 1976.

Price, H.E. Human engineering and system development. Presented at the Product Assurance Symposium of the American Society for Quality Control, San Fernando Valley Section, October 1962.

Price, H.E., Fiorello, M., Lowry, J.C., Smith, M.G., & Kidd, J.S. Department of Defense and service requirements for human factors R&D in the military system acquisition process. ARI RN-80-23. U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandra, VA, July 1980.

Price, H.E., Smith, E.E., & Behan, R.A. Utilization of acceptance data in a descriptive model for determining man's role in a system. NASA CR-95. National Aeronautics and Space Administration, Washington, D.C., 1964.

Price, H.E., & Tabachnick, B.J. A descriptive model for determining optimal human performance in a system. Vol. III: An approach for determining the optimal role of man and allocation of functions in an aerospace system (including technical appendices). NASA Ames Research Center, Moffett Field, CA, March 1968.

SECNAVINST 5000.1A. System acquisition in the Department of the Navy. Department of the Navy, 17 November 1978.

TRADOC Reg. 600-4. Integrated personnel support (IPS). Headquarters, U.S. Army Training and Doctrine Command, Ft. Monroe, VA, 1 June 1978.

Van Cott, H.P., & Kinkade, R.G. (Eds.). *Human engineering guide to equipment design*. Washington, D.C.: U.S. Government Printing Office, 1972.

CHAPTER 4

HUMAN FACTORS RDT&E IN THE TECHNOLOGY BASE AND THE CONTRIBUTION TO SYSTEM DEVELOPMENT

There has occasionally been some concern expressed that Training and Personnel System Technology RDT&E is not fully justified as being necessary to support specific system development. This concern is not directed at human factors in particular, but encompasses manpower and personnel, education and training, and simulation and training devices. Establishment of a clear correlation between the funding and performance of technology base R&D and its utilization in specific systems development is difficult, and is at any rate beyond the scope of this project. However, in the human factors category it is possible to discuss the potential for technology base RDT&E to support specific system development by relating the technology base R&D to the principal human factors products of each phase of system development. In other words, the technology base R&D in human factors should also be identified with:

1. Determining the role of man
2. Allocation of functions to man
3. Task analysis and human engineering requirements
4. Design of optimal man-machine interfaces.

By combining the system phase/human factors products with the DOD classifications for human factors into a matrix, areas of opportunity for human factors and system development have been characterized. This matrix is shown as Exhibit 4-1. Exhibit 4-2 is included to remind the reader what kinds of research are included in each classification. Each cell of this matrix represents an area of opportunity for human factors to eventually contribute to a specific system development.

Exhibit 4-1

Areas of Opportunity for Human Factors R&D
in the Technology Base to Contribute to Military System Development

SYSTEM DEVELOPMENT PHASE AND (↓) HUMAN FACTORS R&D PRODUCTS	CLASSIFICATION OF HUMAN FACTORS EFFORTS		
	HUMAN RELATED	HUMAN-EQUIPMENT RELATED	HUMAN-EQUIPMENT-MISSION RELATED
MISSION ANALYSIS ↓ THE ROLE OF MAN	1	2	3
CONCEPT DEVELOPMENT ↓ MANNED FUNCTIONS	4	5	6
SYSTEMS DEMONSTRATION/VALIDATION ↓ TASK ANALYSIS & HUMAN ENGINEERING REQUIREMENTS	7	8	9
FULL-SCALE DEVELOPMENT ↓ MAN-MACHINE INTERFACE DESIGN	10	11	12

Exhibit 4-2

The Classification System for Human Factors R&D

(Taken from the TCP for FY 1979, see Erickson, Miles, & Secrist, 1978)

Areas	Examples
Human related	Physical characteristics Sensory capabilities Information processing Forecasting job requirements Measures of effectiveness
Human-machine related (subsystem oriented)	Flight instrumentation Equipment layout Maintenance Workload assessment
Human-machine-mission related	Strategic offense and defense command & control Tactical offense and defense command & control Command & control Measures of system effectiveness with inputs

Several things will influence whether the technology base R&D in human factors does in fact contribute to the development of a weapon system (or to the decision not to develop a system). We shall briefly address only two: (1) R&D funding categories, and (2) the auditing method problem. These two were selected because all human factors (in the technology base) is supported by a particular category of funds, and because a cause-effect relationship between research and utilization is a very difficult thing to establish and measure.

R&D Funding Categories

Funding for all technology base areas in DOD is provided within program elements in the budget which provide for funds generally categorized as basic research (6.1 funds), exploratory development (6.2 funds), or advanced development (6.3 funds). DOD defines these funding categories as follows:

> 6.1 Basic Research--scientific study and experimentation directed toward increasing knowledge and understanding in those fields of the sciences related to long-term national security needs. It provides fundamental knowledge for the solution of identified military problems and furnishes part of the base for subsequent exploratory and advanced developments in defense-related technologies and new or improved military functional capabilities.
>
> 6.2 Exploratory Development--includes all effort directed toward the solution of broadly defined problems, short of major development programs, with a view to developing and evaluating technical feasibility.
>
> 6.3 Advanced Development--includes all projects that have moved into the development of hardware for test. The prime result of this type of effort is proof of design concept rather than the development of hardware for service use. Projects in this category have a potential military application.

Advanced development is divided into two subcategories: nonsystem advanced development (6.3A), addressing technological option uncertainties; and systems advanced development (6.3B), which is the design of items (usually hardware) for test or experimentation.

It is very difficult to determine a clear point at which a research and development activity moves from 6.1 to 6.2 to 6.3. The distinction is often somewhat arbitrary. Some research

activities are in fact supported by more than one funding category. Additionally, the individual services have different management organizations and systems for administering technology base funds. Finally, funding categories overlap in time; that is, 6.1 does not end abruptly and 6.2 begin, but rather a project funded under 6.1 may overlap in time with the same project being supported by 6.2 funds. In short, it is not possible to precisely and consistently identify funding categories and research progress for human factors projects in the technology base.

Tracking Research to Utilization

There is no established method for tracking or auditing the results of technology base research to eventual utilization. This is true not only in the human factors or the training and personnel systems technology areas, but in other technologies as well. Two studies will be briefly discussed to illustrate this problem.

The first study was conducted by the General Accounting Office (GAO) in 1977 and was a review of human resources research and development (now the training and personnel systems technology area) in the Department of Defense. The excerpt below was taken directly from the digest of that study.

> Eight Defense research and development organizations identified 374 reports on human resources research and development published during calendar years 1973 through 1975 which were intended to support changes to:
>
> -- regulations, orders, doctrines, policies, or manuals;
>
> -- courses of instruction or training programs; or
>
> -- equipment.

GAO then asked the intended users how the results were used and any reasons for not using them and found that:

-- 56 percent of the reports were used,

-- 38 percent were not used, and

-- 6 percent were being considered for possible use.

The GAO concluded that the Department of Defense could improve utilization by more effective management. The authors of the present report find no quarrel with this conclusion, but do have some serious concerns about the method used to arrive at the results. Those concerns will not be pursued here. Nevertheless, a few points can be made about the review and results as reported in the excerpt above. First of all, if indeed 56% of the reports that were traced <u>were</u> used, this may be a significant and positive finding. Other technology base areas do not fare any better with the utilization of their reports. A second point is that all research and development does not find its way into eventual utilization. A very valuable payoff from research and development can be in the form of negative findings, which stop the research itself or stop the development of some system. Third, the GAO review was confined to reports published from 1973 to 1975, and it is the opinion of the present authors that some of the 38% not used will eventually find some utilization. One has to be more patient when establishing the relationship between research and utilization.

The second study was also conducted in 1975, by the National Heart and Lung Institute (NHLI) (see Comroe and Dripps, 1975), and was concerned with the top 10 clinical advances in diagnosis, prevention, and treatment of diseases of heart, blood vessels, and lungs. This was a four-year study to analyze what knowledge was required for the great advances since the early 1940s. Over

150 experts screened 4,000 scientific articles and then analyzed 529 of these that they considered to be essential for the top 10 clinical advances. Of the 529 key articles:

- 41% reported research that at the time was unrelated to the later clinical advance (non-targeted research)
- 61.8% described basic research
- 21.2% were clinical investigations (targeted research)
- 14% were concerned with the development of apparatus techniques or procedures
- The key articles range in time over 200 years, with many important ones being published as long as 75 years ago.

The important points about this study are fairly obvious. At the time it was performed, 41% of the reported research was unrelated to the problem it later helped to solve. And 21.2% of the research, while clinical in nature, was unconcerned with the fundamental issues. Also notable is the range of time (200 years) that the eventually related research covered.

The NHLI investigators also point out that a major defect in education and science is the perpetuation of the "one man equals one discovery" myth (e.g., Marconi equals wireless; Bell equals telephone).

Inferences about the technology base R&D efforts in human factors that are based on the NHLI study results are certainly limited. Clearly, the quantitative results of one are not applicable to the other; however, the difficulty in auditing or tracking cause-effect relationships is similar.

Illustrations of Contributions
from the Technology Base
to Specific System Development

To conclude the discussion of human factors R&D and the technology base, it is interesting to note that the value of the research conducted in each cell of Exhibit 4-1 could be assessed by the contribution that the research makes to specific system developments over the years. Again, no matter how interesting it may be, measuring the value of this contribution is not within the scope of this project. Nevertheless, it is meaningful to qualitatively emphasize the relationship of human factors in the technology base to system development products. To this end, we will try to present a brief illustration for each cell in the matrix. The illustrations which follow are keyed to the numbers in the cells.

Block 1. Human related R&D in the Mission Analysis Phase: measuring human tolerance to motion to assist ship design and development.

Need. The Navy is investigating experimental designs of surface effect ships (SES). A design constraint which requires human factors R&D previous to any prototype development is determination of human stress tolerance to motion and associated human performance capabilities while in moderate and high sea states.

Research. Research has begun on human tolerance to degrees of SES motion, using a motion generator for simulation. In addition, techniques for measuring complex human performance have been developed to assess the ability of Navy personnel to perform shipboard tasks during extended exposures to such motion.

Utilization. This human factors R&D will have direct implications for the design of SES subsystems. It is also envisioned to have an impact upon ship operations.

Block 2. Human-machine related R&D in the Mission Analysis Phase verifying warning system audibility.

Need. In the absence of quantitative data, the Air Force was concerned with the adequacy of the current auditory warning systems to offer advanced indication of a missile propulsion system toxic propellant leak to operating personnel located in missile silos. A portable vapor detector was used to detect such leaks and to sound an auditory alarm. Concern was expressed over the possibility that individuals working in silos with ambient noise levels of 73 to 89 decibels might not be able to hear the alarm. Consideration was being given to development of a new, more elaborate warning system.

Research. In order to properly evaluate the requirement for a new warning system, human factors R&D was needed to determine the adequacy of the current system, before initiating development of an essentially new, alternative system. Toward this end, a field study of the actual system was performed utilizing operational personnel to report when they heard the alarm. Results indicated that the personnel heard the alarm each time it was sounded and made no false reports.

Utilization. Consideration of possible new system development was abandoned. Cost estimates for development of the alternative system for 500 silos ranged from $250K to $1,000K. Cost savings achieved through elimination of an unnecessary system development program were due to a study costing aproximately $1,000.

Block 3. Human-machine-mission related R&D in the Mission Analysis Phase: Development of an automated command, control, communication, and intelligence (C^3I) system.

Need. In order to develop a computer-based C^3I system for automated battlefield support, the Army had a requirement for human factors R&D to develop a data base covering mission related human performance and human-machine concepts. Due to unique problems posed by such a system, data base concepts are required which: (a) identify human user input and output capacities, and (b) offer maximum real control over the battle.

Research. Simulations for automated C^3I were developed to offer expected mission scenario simulation, identify the role of man in automated C^3I systems, demonstrate operator task feasibility, and determine optimal design criteria for the man-machine interface. Examples of results include:

- Guidance for input and display data
- Guidance for military terms abbreviation to reduce workload and errors
- Use of embedded training
- Comparisons of data summary methods (e.g., graphic displays)
- Tradeoff criteria between critical data retention and expanded data retention
- Recommendations for data reduction and purging to facilitate system performance.

Utilization. Data base information accrued from simulation research on the automated C^3I was furnished to Army developers to aid in system development as concept guidance and criteria for automated C^3I systems. These systems are expected to facilitate human ability to govern combat on the ground.

Block 4. Human related R&D in the Concept Development Phase: Visibility requirements for underwater information displays.

Need. Recent advances in diving technology (e.g., free-floating manned submersible) have created a requirement for human factors R&D on underwater vision related to display design. These technology advances, tied to reduced visibility and lack of a data base sufficient to guide underwater visual display design, combine to threaten Navy diver mission success and life support.

Research. The research program that was initiated encompasses both display requirements and basic experiments on visual performance underwater. Water turbidity simulation techniques were developed to simulate harbor and oceanic waters. Since number reading and signal detection were identified as the most critical display-oriented tasks, experiments based on these parameters were constructed that revealed the following: brightness was the strongest legibility factor, green was more legible than red, and only harbor turbidity had a major effect on legibility.

Utilization. This continuing line of research has resulted in wide distribution of information to both research and fleet operational communities, whose responsibility it will be to implement these findings into displays to be used in ambient undersea environments such as instrumentation in new and existing diving systems. System-to-diver and diver-to-diver communication will also be facilitated by these experimentally derived guidelines.

Block 5. Human-machine related R&D in the Concept Development Phase: Selected problems in armor operations and design.

Need. A number of problems with potential impacts on armor operations and design have been identified by the Army. Examples are: concern with the effects of external environmental conditions on the internal environment of a buttoned-up tank, and concern with the adequacy of current escape and evacuation systems.

Research. In order to assess the environmental effects upon tank workspace, data on internal temperature and humidity were obtained using a recording hygro-thermograph. These data were compared with comparable external conditions. Results showed that temperature and relative humidity inside a tank lag behind the external conditions by approximately three hours.

In addition, opinion data were obtained from crewmen concerning the adequacy of escape and evacuation systems and potential design changes. One conclusion was that if a tank were hit, the gunner will be the most vulnerable and would have the greatest difficulty escaping. Also revealed was that lifting straps should be added to uniforms for evacuation of wounded, and that escape/evacuation training was extremely limited.

Utilization. This information could play a role in future design of new tanks as well as in current training and operations. Especially in the case of tank crew escape/evacuation, design recommendations could have an impact.

Block 6. Human-machine-mission related R&D in the Concept Development Phase: Effects of operator interface on system cost-effectiveness.

Need. The lack of availability of a reliable technique to aid in design tradeoff decisions at the man-machine interface of system development has resulted in a Navy need for computer models to simulate operator characteristics. In order to be useful, such a model must be able to determine whether a proposed or potentially modified system will result in a net gain in effectiveness over cost, as well as to choose the most cost-effective alternative means of achieving a specific performance level, when the operator's job is considered.

Research. Human factors R&D has developed an Operator Interface Cost Effectiveness Analysis model which is capable of calculating the interactions between a human operator (including control/display location, procedures, decisionmaking, observation, recall, and physical movement), system hardware, and software, as well as specific mission events. It has been applied to evaluate alternate mission equipment configurations. For example, two forward-looking infrared (FLIR) sensor configurations for the P-3C surveillance aircraft were evaluated using this model. Results showed that one configuration was superior due to:

- Less operator disruption in other tasks
- Less time to perform mission
- 25% less costly to operate.

Utilization. As illustrated in the example provided, this model promises substantially improved performance for Navy manned systems as well as substantial cost savings by preventing development of inferior hardware at the man-machine interfaces. It is also being used in other system development programs for the Navy.

Block 7. Human related R&D in the Demonstration and Validation Phase: Noise limits for Army materiel.

Need. Intense sound accompanies many aspects of military operations and training. Due to hearing loss which occurs as a result of abusively loud noise and/or lack of effective hearing protection devices, the services have a requirement to initiate hearing protection and auditory research. This is especially so for design-related research with intent to reduce noise through design guidelines.

Research. The Army initiated research into noise effects, limits, measurement, and testing techniques as well as hearing protection. This began with an accumulation of existing noise guidelines and other information (such as industry standards covering the topic) and continues today with research to fill gaps in hearing technology. Continuing development of the auditory and noise data base has resulted in the initial and revised publication of MIL-STD-1474, Noise Limits for Army Materiel. Plans are currently underway to raise the standard to encompass DOD-wide application.

Utilization. The use of this standard should result in a significant reduction in the present 40-50 million dollar annual expenditure in hearing loss compensation paid by the VA to military veterans. In addition, this noise research has paid off in the development of a prototype high compliance idler for tracked vehicles designed to reduce noise emanating from the axle and track location.

Block 8. Human-machine related R&D in the Demonstration and Validation Phase: Human factors in redesign of a ground infantry weapon system.

Need. The Army had a requirement for human factors R&D on the DRAGON antitank missile system. Desired weapon improvements included means to increase target "hit rate," or accuracy, as well as to make it more portable. Portability was important given that the weapon system is to be employed by ground infantry to counter tank threats.

Research. Human factors R&D was implemented to investigate means to improve DRAGON missile system accuracy. These efforts resulted in the redesign of portions of the weapon system. For example, a lightweight tripod/viscously damped mount was developed to replace the previous non-human engineered configuration. In addition, redesign efforts resulted in a weapon system capable of folding into a lightweight, compact package easily portable by one individual.

Utilization. Field tests show that the human factors redesigned DRAGON weapon system yields a 30% increase in hit rate as compared to the previous design. The tripod modification provides a precision tracking capability for a gunner that will substantially improve his ability to hit distant moving targets. Design improvements in portability and compactness will facilitate transport of the weapon system.

Block 9. Human-machine-mission related R&D in the Demonstration and Validation Phase: V/STOL human factors planning.

Need. Navy interest in developing a viable V/STOL aircraft has resulted in a need for human factors R&D to support human factors design of the aircraft. One reason for this is the taxing workload demanded of pilots, creating a "pilot factor" crucial in design and operation of this type of aircraft. Contrary to expectation, the accident rate for this development program was also increasing. Pilot factor contributed heavily to this problem.

Research. In reaction to this state of affairs, the Navy initiated a program to provide human factors R&D support to the human factors design of the V/STOL aircraft. A major activity has been the compilation of a data base of available documentation to support the program. The data base identified pilot workload as a critical issue. A "primer" was also developed which introduced V/STOL technology and operation to human factors personnel.

Utilization. This effort has contributed to the human factors data base for V/STOL aircraft. In addition, human factors personnel involved with V/STOL aircraft design were offered job performance aids. This line of research should contribute to an ultimate reduction in "pilot factor" accidents.

Block 10. Human related R&D in the Full-Scale Development Phase: Information display for landing signal officers (LSOs).

Need. A Landing Signal Officer (LSO) standing aboard an aircraft carrier must guide a carrier pilot and aircraft into an appropriate approach to a landing and then make a time-critical decision (in seconds) as to the safety with which this rapidly approaching aircraft may land on the carrier. These decisions have traditionally been based upon a limited assortment of visual and auditory cues. In addition, approach and landing speeds are high; and perceptual cue availability is adversely affected by night and/or adverse weather conditions. Due to annual accident rates associated with carrier landings, the Navy has a requirement to aid LSOs by developing supplemental information displays.

Research. Detailed investigations involving task analysis were conducted of the requisite visual and auditory cues and associated judgments made by LSOs when guiding the aircraft's approach. The resulting information was incorporated into an innovative, see-through, head-up display system which provided the LSO with these critical parameters, without interrupting his visual tracking of the approaching aircraft.

Utilization. Operational evaluations were conducted on the display system by actual LSOs. Results indicated overwhelming approval by potential users. These users are confident that the display system will facilitate safe and efficient landing operations, thus reducing accidents, associated losses in equipment and personnel, and reduced costs. The system is to enter production and be fielded on all carriers.

Block 11. Human-machine related R&D in the Full-Scale Development Phase: Man-machine integration technology.

Need. Due to advances in airframe, flight control, and avionics technologies which promise to revolutionize aircraft capabilities, the Air Force has a requirement for human factors R&D to improve areas of man-machine integration technology such as aircrew visibility. Additional areas concentrate around a need to improve tactical aircraft cockpit, controls, and displays. In addition, methods to measure pilot workload under different configurations need to be identified.

Research. The feasibility of a voice activated switch of a weapon system was demonstrated towards improvement of aircraft cockpit controls and displays. These results led to a request for voice controlled switching for the A-10 pilot during weapon delivery. In addition, an improved pilot/fire control interface combining voice activated switching and helmet-mounted sight and fire control status displays to facilitate continuous pilot out-of-the-cockpit vision is being developed. Methods are being developed to measure pilot workload under different cockpit configurations. Part of this effort has produced a set of symbols that present order-of-battle information to a pilot rapidly and accurately.

Utilization. Improvement to aircraft cockpit, controls, and displays and increased data base development of pilot workload capabilities for various cockpit configurations has immediate application as well as application to future systems.

Block 12. Human-machine-mission related R&D in the Full-Scale Development Phase: Human factors R&D support for FIREFINDER radar.

Need. The Army has developed the FIREFINDER radar to pin-point enemy indirect fire weapons. Mission success is contingent upon a fast reaction time which makes human performance capability at the man-machine interface critical. As a result, human factors R&D was required to support system development.

Research. A task analysis for FIREFINDER was developed, tested, and refined to keep up to date with system hardware reconfigurations. Army human factors personnel coordinated with FIREFINDER training simulator developers to support design of a training effective simulation system. For example, the simulator's basic training effectiveness was confirmed using operational personnel in operational test and evaluation previous to delivery of the final simulation system. Additional deficiencies were identified and corrected at the contractor's plant.

Utilization. The FIREFINDER task analysis is in use by the Army for developing operator/maintainer training courses. The simulator now in use by the Army is a more effective trainer, with the pre-identified deficiencies corrected, than it might otherwise have been.

References

Comroe, J.H., & Dripps, R.D. Top ten clinical advances. Contract 1-HO-1-2327. National Heart and Lung Institute, 1975.

Erikson, R., Miles, J., & Secrist, G. Technology Coordinating Paper: Training and personnel technology. Department of Defense, August 1978.

General Accounting Office. Human resources research and development results can be better managed. FPCD-77-43. April 1977.

CHAPTER 5

DERIVING METRICS FOR MEASURING THE VALUE OF HUMAN FACTORS IN MILITARY SYSTEMS DEVELOPMENT

The previous chapter described a conceptual basis for identifying the contribution of human factors in military systems development. The major question to be addressed now is: Can we measure that contribution? This question will be answered by two successive discourses. The first, presented in this chapter, deals with metrics for describing human factors value. The second, presented in the chapter to follow, develops a methodology for measuring human factors value.

The objective of this chapter is to demonstrate that system design and human factors criteria and terminology are compatible, and that a vocabulary for human factors impact assessment can be constructed from engineering and human factors by means of common and complementary terms.

This chapter presents the results of a literature review to compile terms useful for describing human factors R&D products and impacts, compares those terms with conventional system engineering and design terminology, and derives a preliminary vocabulary to define human factors R&D impacts on military systems.

Background

The importance of objective, quantitative data for decision-making in the system development process is apparent to anyone involved. The presence of formal mathematical models or their near equivalent has permeated every level of system development, from the engineering draftsman to the top levels of the Department of Defense. New management techniques supported by quantitative measurement have evolved rapidly over the past 40 years.

A parallel process has been occurring in the behavioral sciences that undergird human factors applications. There has been a consistent emphasis during the past 40 years on rigorous measurement and, in effect, an attempt to emulate the physical sciences with respect to precision.

While significant strides have been made (for example, in scaling techniques) there is really no valid prospect that the behavioral sciences will ever "catch up" to the physical sciences in the matter of precision because of the inherent characteristics, such as high variability, in the phenomena of concern.

This circumstance generates a chronic problem for those concerned with the contribution of human factors to military systems development. In current parlance, the problem is the synthesis of "soft" measures from the psycho-physiological domain of human factors with the "hard" measures presumably available to systems engineers.

This study establishes a basis for an operational synthesis of those measures. The three essential components of this basis are:

1. A formal relationship of explicit human factors products with the system development process. Chapter 3 develops the relationship of principal human factors products for the major system development phases. The premise of the relationship is that both human factors and systems engineering are components of the system development process.

2. A methodology with techniques that integrates "soft" and "hard" measures. The methodology presented in Chapter 6 is designed for the formal treatment of quantitative and qualitative impacts.

3. A set of metrics to describe human factor impacts and to define parameters for the modeling process. This chapter addresses the derivation of metrics for describing and measuring human factors impacts on military systems development.

Identifying and Defining Metrics

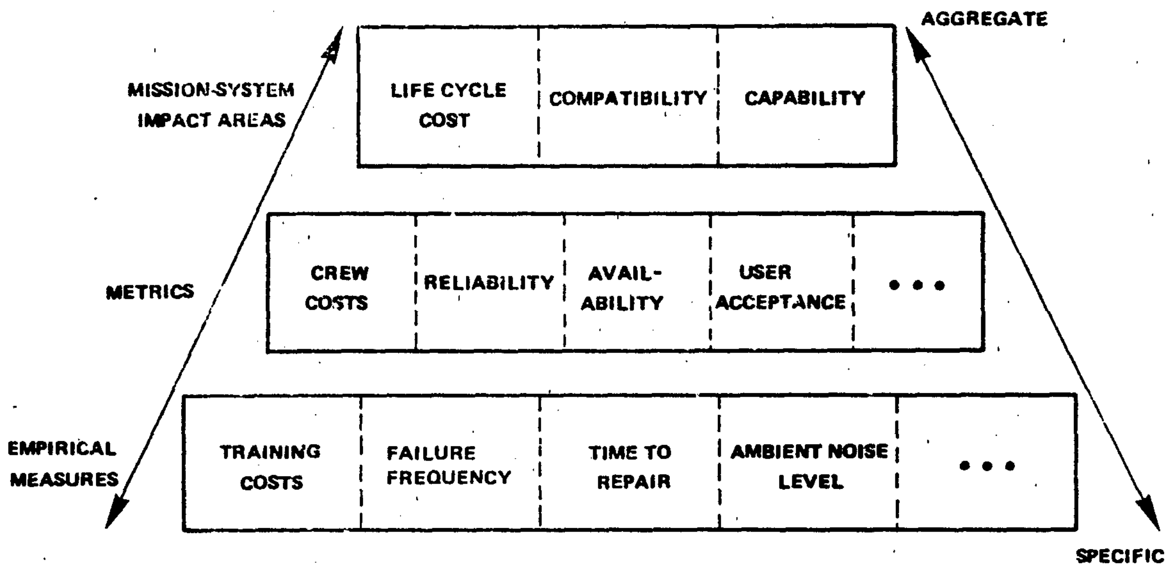
The discussion in previous chapters and in DOD documentation leads to the assertion that any human factors or design engineering change must ultimately be assessed in terms of its contribution to the system-mission. At the system-mission level, three impact areas have been identified: cost, capability, and compatibility. These impact areas represent categories to aggregate or embed all the effects on the military system of separate design and/or operations support analyses. They are intended to represent the "bottom-line" effects of system changes (or choices), and we use them in this derivation of metrics as the most broad terms in a measurement vocabulary hierarchy.

The three impact areas represent distinctive effects of a change on the system-mission. However, the effect from a single human factors or design engineering change will often be relatable to several or all of the impact areas. Notionally, an improvement in operator-system compatibility could enhance the mission-system capability and also lead to fewer operator-induced repair actions, thereby reducing repair costs.

The terms at the lowest level of our hierarchy represent empirical measures. They are representative of the dependent variables that human factors researchers have used for many years; but such empirical measures are not always easily identifiable with system effects. Therefore, it was decided that we need an intermediate level in our measurement hierarchy that is acceptable to both system developers and human factors professionals. The intermediate level of terms is defined as metrics. Exhibit 5-1 illustrates the three levels of our hierarchial measurement vocabulary.

Exhibit 5-1

Hierarchical Relationship of Impact Areas, Metrics, and Empirical Measures



The desirable characteristics of metrics have been determined to be the following:

1. More specific than impact areas (i.e., the principal focus or objective of an analysis).
2. Representative of the direct result of an analysis or experiment.
3. Relevant to the human factors principal products.
4. Compatible with the conventional terminology of system engineering.
5. As mutually exclusive as possible.

Characteristics 1 and 2 imply that a metric is the output of a model or experiment or some other analysis. In these cases, the metric is a function of some lower level parameters or empirical measures. Characteristic 3 implies that metrics must be relevant and suitable to the human factors efforts. The metrics must be familiar to human factors researchers and practitioners and allow for realistic interpretation of the changes under consideration. Characteristic 4 implies that measurements common to systems engineering and human factors are to be represented by a single metric. Thus, system engineering and human factors considerations are integrated within common metrics. This clearly has implications for the modeling of these integrating metrics, a subject discussed elsewhere in this report. Characteristic 5 is a desirable property that, if satisfied, implies that definitionally one metric does not overlap with another. We recognize that this characteristic is a particularly difficult one to satisfy, and is one that will only be approximated by our preliminary vocabulary.

These characteristics were interpreted as selection criteria in the derivation of the preliminary vocabulary.

Literature Search and Data Base System

We used an empirical approach to derive the metrics. It entailed collating actual terminologies in the fields of human factors research, human factors engineering, and systems research. The literature review was followed by the development of a data base tailored specifically to human factors in military systems development. Traditional publications for human factors research provided a wealth of data on specific empirical measures and metrics. Computer printouts were obtained from the National Technical Information Service (NTIS) and the Defense Technical Information Center (DTIC). Documents containing extensive

bibliographies were also reviewed for pertinent citations. In addition, an intensive effort was made to identify and obtain pertinent government directives, instructions, standards, and guidance documents. This literature review resulted in the identification of more than 350 relevant documents. Subject matter categories included: human factors engineering; costs; military system developments/acquisitions; test and evaluation; man-machine studies; and system analysis, design, and development.

The products of the literature searches were used to develop a data base. The data base was the primary instrument used to analyze the selected material and derive a set of empirical measures and metrics. The following general documentation categories were accumulated for purposes of review and assessment, and were put into the computer data base:

1. Technical documentation--including technical reports, papers, memorandums, bibliographies, professional journal articles, and technical books.

2. Policy documentation--including Department of Defense directives; instructions; pamphlets; military specifications and standards; and individual service instructions, regulations, and pamphlets.

   2a. Guidance documentation--including DOD and individual service military handbooks, guidebooks, manuals, and pamphlets.

3. Work Unit Summaries (DOD Form 1498).

4. Informal documentation--including proceedings of various conferences and meetings, unpublished literature, and personal testimonies.

Screening and Selection Process

The candidate terms derived from the documents collected were sorted and grouped. The first screen applied was a frequency of use check. All low frequency-count terms were reviewed for usage; terms not explicitly described by the author were deleted.

The terms remaining after the first screening were then defined using the following procedure:

1. Quantitative measures were defined according to (a) their unit of measure or dimension and (b) constraints (e.g., time period, events, cycles, etc.) and special circumstances for their use (if any), such as unique usages (e.g., location).

2. Qualitative measures, subjectively determined, were put through an additional review. Checks were also made to determine if such measures had a quantitative counterpart or could be tied to some underlying dimension. Whenever characteristic constraints and special circumstances for use of these measures were discussed in the original document, this information was included in the analysis.

3. Following this procedure, the list was examined to ensure that sufficient information was available about each term to avoid ambiguity.

Derivation of Metrics

The next step entailed the derivation of metrics. Criteria reflecting the five metric characteristics were applied to the list of empirical measures. A partial list of candidate measures

and associated definitions is given in Exhibit 5-2 (the complete list is in Appendix B). A list of the derived metrics is given in Exhibit 5-3. In each list measures and metrics common to system engineering and human factors have been grouped as system related, and those principally used in human factors grouped as personnel related. The list of metrics is a preliminary one, and in subsequent analyses and case studies it should be refined. Each of the metrics is relatable to several empirical measures. Exhibit 5-4 illustrates several of the functional relationships observed in the literature reviewed.

Exhibit 5-2
Sample of System-Related Terms and Associated Dimensions (Unit of Measure)

ACCESSIBILITY	subjective: satisfactory/unsatisfactory ease of admission to various areas of an item
ACCURACY	probability/frequency of documented error
CAPABILITY	subjective: mission objective achievable given the condition during the mission
COMPATIBILITY	subjective: ability of items of equipment to coexist (including effects of temperature and moisture
CRITICALITY	subjective: relative degree of task importance for mission succes
DURABILITY	probability: item will survive a) its projected life b) overhaul point c) rebuild point without a durability failure (failure that causes an item to be rebuilt or replaced
EASE OF USE	subjective: tasks associated with simplicity, readability, etc.
FAILURE RATE/FREQUENCY	1) number of failed items 2) number of effects (out of tolerances) per month, week, hour, etc.

Exhibit 5-3

Preliminary Metrics Derived from the Literature

SYSTEM-RELATED METRICS

- AVAILABILITY
- RELIABILITY
- READINESS
- DEPENDABILITY
- EFFECTIVENESS
- MAINTAINABILITY
- PERSONNEL ACCOMMODATION/ENHANCEMENT
- DESIGN/PRODUCTION (PRODUCIBILITY)
- SYSTEM RUGGEDNESS
- OPERABILITY

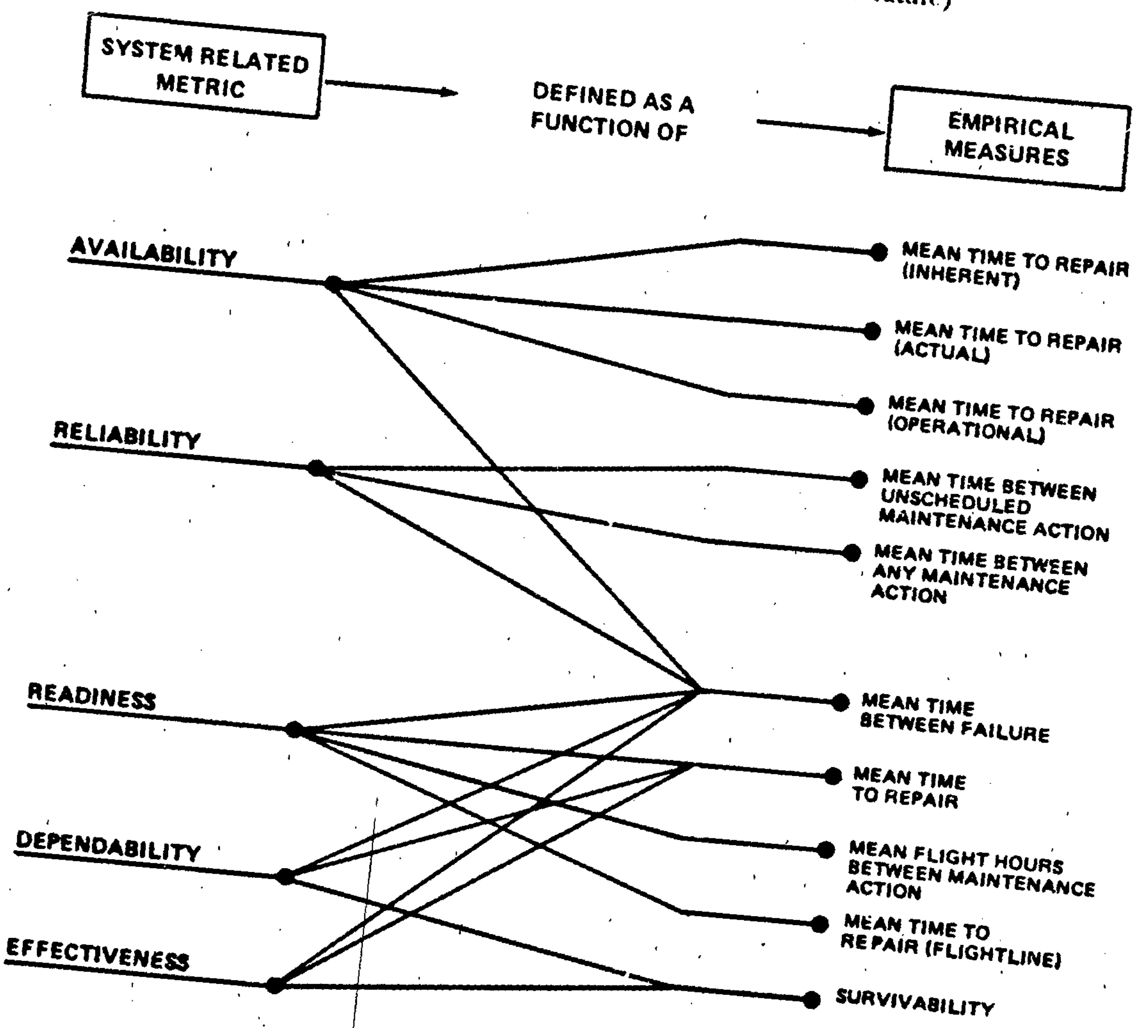
PERSONNEL-RELATED METRICS

- HUMAN PERFORMANCE
- SKILL, GENERAL
- SKILL, MAINTENANCE
- TASK LOADING
- PHYSIOLOGY/PERCEPTION
- ENVIRONMENTAL FACTORS
- OPERATIONS FACTORS
- MOTIVATION/SOCIAL/ORGANIZATION FACTORS

Note: This list represents an initial attempt to construct a set of metrics for human factors and system engineering. All the system-related metrics are common to engineering and human factors, and the personnel-related metrics are principally related to human factors.

Because of the high saliency of the cost issue, the inherently quantitative properties of cost assessment, and the relatively low ambiguity associated with the cost concept, the derivation of cost metrics and measures was more straightforward than for the other metrics.

Exhibit 5-4
Sample Relationship Among Selected System Related Metrics and Empirical Measures (As Found in the Literature)



The literature of system evaluation contains many detailed cost structures. It was convenient to use the generic life cycle cost structure developed by Fiorello and Betaque (1977). That structure reflects current usage in the DSARC process, and is presented in Exhibit 5-5.

Each of the impact areas is discussed in the next section. Brief illustrations are given of the relationships among derived empirical measures, metrics, and impact areas.

Exhibit 5-5

System Life Cycle Cost Impact Area for a Weapon System

SYSTEM LIFE CYCLE COSTS

- **100 RESEARCH AND DEVELOPMENT**
- **200 INVESTMENT**
  - **201 Weapon System Investment**
  - **202 Support Investment**
- **300 OPERATING AND SUPPORT**
  - **301 Deployed Unit Operations**
  - **302 Below Depot Maintenance**
  - **303 Installations Support**
  - **304 Depot Maintenance**
  - **305 Depot Supply**
  - **306 Second Destination Transportation**
  - **307 Personnel Support and Training**
  - **308 Sustaining Investments**

Source: Fiorello & Betaque, 1977.

Note: In the terminology used in this report, life cycle cost is the impact area; the cost categories at the 100, 200, and 300 levels are analogous to cost metrics; and the lower level cost elements are analogous to empirical measures.

Impact Areas, Metrics, and Related Measures

Capability Impacts

The impact area called capability has a clear-cut tie to the man-machine-mission performance of a new system.

There are many examples of the linkages between the measured capability of the human and the ultimate performance of the system during the mission operations. Many different categories of behavior have been examined in many different system contexts. A particularly good illustration can be derived from the focus on the human operator in a controlling or decision-making role in command, control, communications, and intelligence (C^3I) systems. Specifically, the case involves radar signal processing. Radar system functions (i.e., missions) include ground control of tactical air strike operations, interceptor operations, and return-to-base operations in adverse weather or poor visibility conditions.

So-called "raw" radar returns are indiscriminate in the sense that the indication of the position of one aircraft on the radar display looks just like the indication of every other aircraft in the same coverage load. Under low traffic loads, radar controllers are able to "keep track" of the identity of the aircraft represented by a particular return "in their heads." Under medium loads (approximately seven simultaneous "targets") or higher, the controller becomes prone to errors of identification, and system performance consequently degrades rapidly.

During the early applications of radar, it was possible to compensate for this capacity limitation by the use of manual plot boards or plotting tables. The job of directing the movement of interceptors was divided into three main requests. The radar

operator (1) reported "target" positions to a plotter (2) who moved coded markers. The controller (3) made decisions based on the representational display provided by the plotting board.

In the mid-1950s, it was conceived that it was possible to put a computer between the radar signal and the operator. The computer could be given the burden of "remembering" the identity of a target and generating a display such that the identity was reliably associated with position. There followed a major sequence of human factors contributions that: established precisely what the consequences were for overall system effectiveness, specified how much information should be tied to each target (e.g., altitude as well as identity), directed the formatting and coding of the information, and defined backup procedures in the event of a subsystem failure.

Empirical measurement in this case was carried out primarily in the context of real-time simulation experiments. The specific variables measured were the average delay in transit during return-to-base operations and error counts, defined by the instance of two aircraft coming into a predetermined proximity relationship.

The metric level in this case would be represented primarily by effectiveness and operability. These, in turn, would feed into the impact area of capability.

Cost Impacts

At the mission-systems level, the cost impact area is defined by the life cycle cost of the system; in other words, the total cumulative cost of bringing a system into being and using it over its operational life.

Human factors engineering typically accounts for a small fraction of the cumulative cost. The outlay of funds is used to support the generation of human factors products, during the design stages of system development, and for specialist participation in test and evaluation.

The specific engineering inputs from human factors sources may impact the development and production costs (both positively and negatively). For example, it is possible that the layout of displays and the controls on an instrument panel that is optimum from a human factors point of view can be more or less difficult to fabricate during production or could require more or less expensive components. However, it is actually more likely that what turns out to be optimum from a human factors viewpoint is also optimum with respect to economy of production. Moreover, the possible additions to cost tend to be relatively insignificant when compared to some of the cost avoidance potential inherent in successful human factors contributions.

Any number of actual or hypothetical cases could be cited in which human factors considerations contributed to a significant reduction in life cycle costs. For example, the size of the operational crew for any given weapon system is a question that links human factors considerations to economic consequences. The larger the crew, the higher the life-cycle costs will be; but an arbitrarily small crew might not be able to handle peak work loads during crucial mission stages. Work load capacity limitations are the kind of specific products that can be generated in a rigorous manner through the proper application of human factors procedures. Such estimates should not be made by rule-of-thumb or guesswork.

The quality of performance (inverse of error frequency) on the part of crew members in different crew size and organizational arrangements can be measured empirically. The context of measurement can vary from rough task simulation in laboratory settings to observations in the field of actual operations. The results of such observations can contribute to the overall system design deliberations in several areas, but in the present framework the critical linkage is to cost factor 301, costs associated with deployed unit operations (see Exhibit 5-5). Once that linkage has been made, the logic of aggregation to overall life cycle cost is straightforward.

The final point to be made is that the cost impact could be forecast with little ambiguity once the crew size decision has been made.

<u>Compatibility Impacts</u>

Compatibility is, in general, the most complicated of the three impact areas. It is complicated because there are three distinct but interrelated facets involved: physical, physiological, and psychological compatibility.

<u>Physical Compatibility</u>. Physical compatibility relates to the human component as a physical object. The major resource for the conduct of tests and analyses of physical compatibility is anthropometric measurements. An example can be drawn from the design of the cockpit ejection subsystem for a high-performance jet interceptor aircraft. The problems involved in such a design are many. The routine for activation must be simple because the pilot is under severe distracting stress when activation is required. The ejection module must clear the aircraft in such a way that there is no impact with the aircraft structure and must stabilize so that parachute deployment is not impaired.

As was indicated in Chapter 2, cockpit size is shrinking as a general trend. One ejection subsystem design recently proposed met all the complex requirements except one. The trajectory of the module was such that as the pilot cleared the cockpit the first few inches of the toe portion of the flying boot came in contact with the edge of the instrument panel. The impulse force was sufficient to shear off the boot tip and the pilot's toes with it.

In this case, as in others, it requires no elaborate computational model to conclude that a better, more comprehensive application of anthropometric data would improve the design of this subsystem. The consequences for system performance are similarly clear.

<u>Physiological Compatibility</u>. It is convenient to use the discussion of physiological compatibility to make the distinction between capability and compatibility a bit clearer. This distinction can be accomplished by considering the human factors design parameters of an armored personnel carrier. In such an instance, it is useful to temporarily separate the functions of the operator from those of the rider or passenger.

The mission of the system is to deliver the passengers in an unimpaired condition to some locale under hostile conditions. The key attribute of the passengers is that they are not in control during the journey. In effect, they are passive cargo. But there are many ways in which the design of the system can be either compatible or incompatible with their physiological characteristics. For example, when traversing hostile territory in a combat situation, the vehicle will be "buttoned-up" in the sense that all hatches and doors will be closed. Such a closed environment creates a potential limitation of effective fresh air

circulation. The vehicle itself is a potential source of toxic gaseous air contaminants (e.g., carbon monoxide). Hostile action can generate other toxic airborne chemicals. In such a case, the human factors engineering role would be to inventory all possible sources of toxic contamination. The analysis would include a full range of adverse circumstances that could arise from the terrain, weather, and hostile action.

It is conceivable, but unlikely, that such a design review would indicate a zero hazard potential in the "buttoned-up" mode. If the hazard potential were present, then certain design options such as compressor-powered ventilation systems could be evaluated. That is, the cost and complexity of the ventilation process could be weighed against the estimated probability of a hazard arising in operations, the intensity of such a hazard, and the consequences to the mission if the hazard were not eliminated.

During the design and prototype stages of system development, the empirical level measures would come "from the book" in the sense that the human vulnerabilities to toxic compounds are well known and documented. Other parametric considerations such as the likelihood of inflammation of hydraulic fluid due to mishap or enemy action would have to come from other members of the design team. During field trials of prototype models, however, a reasonable empirical test could involve the actual sampling and chemical analysis of the air in the interior of the vehicle during combat exercises.

Finally, an analogous approach could be taken to a list of other potential physiological hazards: temperature extremes, noise, vibration, and acceleration stresses. While such a thorough analytic and empirical review might be considered burdensome, the potential negative consequences of the delivery of exhausted, disoriented, or incapacitated troops into a fire zone are clearly worth the trouble to avoid.

Psychological Compatibility. Psychological compatibility has two component parts: behavioral and attitudinal. The question of behavioral compatibility can be illustrated easily by an example of the use of technical documentation by maintenance technicians. From a system development standpoint, the initial empirical data needed would be in the form of a distribution function of the reading skill levels of the population of assignable technicians.

The rather obvious human factors recommendation would be to match the difficulty level, and in particular the vocabulary of technical documents, to the relevant skill level of the user population (i.e., the tenth percentile or the second stanine level and above). During early system development, design criteria could be met by the imposition of a "control" vocabulary on the preparers of the technical documents. During later stages (validation and verification), empirical tests of the readability could be conducted using representative technicians from the prospective user population.

Increasing the compatibility of technical documentation can result in substantive improvements in weapon system cost and availability. An example is the experience of the avionics maintenance improvement team with the avionics suite on the F-111D. Re-test-OKs were averaging over 44% and were reduced by 15% due to improving the technical documentation.

Attitudinal compatibility is somewhat harder to illustrate, and it is a matter of some dispute whether or not even strong negative attitudes on the part of a system operator can be a significant problem when that operator is under military discipline. However, in the recorded history of the interaction of military personnel and their equipment there have been instances

wherein system performance suffered because of the users' negative attitudes. A modern example of user acceptance, or attitudinal compatibility, can be drawn from an article that appeared in the *Armed Forces Journal* (April 1978). Because of its brevity, an exact excerpt of the article is included below.

> ARMY'S PIERRE: "FIX BAYONETS!"
> DOESN'T COME ACROSS ON THE COMPUTER
>
> It is easy, in tossing around the acronyms and technical terms associated with developments in command, control, and communications to lose sight of their purpose: to help human beings perform their tasks. Dr. Percy Pierre of the Army puts it this way:
>
> > 'We seem to have disguised equipment that performs reasonably understandable functions behind a variety of unpronouncable acronyms and names (like digital multiplexer) that are only meaningful to those familiar with the technology.'
>
> Pierre, like so many others consulted for this issue, cautions that voice transmissions will still be required on the battlefield, no matter how far into the future one projects, or how extensively commands and information are converted into digital forms. He told Congress recently, for instance, that "Follow Me" or "Fix Bayonets" are commands that do not convey the same impact when received in a computer printout.
>
> The human's desire to hear another human voice in a time of crisis held back deployment of an advanced, digital device a few years back. According to experts at one of the leading electronics companies, their engineers had developed a tiny two-way radio device that could be used at rifle company and platoon level to send and receive messages in formatted form. So, if a leader wanted to call for artillery fire mission, he just punched in a code and the device sent it. He received acknowledgement with a beep signal. The device worked well, but it failed in field tests. The troops didn't want a beep when they called for help--they wanted to request the fire mission by voice in order to express their urgency, and they wanted a calm human voice telling them that the rounds were on the way, not a beep. They distrusted the beep, since it could have been caused by a malfunction in the system.

Summary

The principal message in all of the preceding examples has been that it is possible to proceed both upwards and downwards on the "ladder" of measurement aggregation. Each type of military system will involve different specific measures and different patterns of linkage from one level to another. However, it is demonstrable that the linkage can be made. The analysis can be focused at the level of discourse employed by systems designers and program managers to assess the systems upon which they are working. The procedure by which specific evaluation of the human factors contribution can be made is discussed in the next chapter.

References

Armed Forces Journal International. Army's Pierre: "Fix bayonets!" doesn't come across on the computer. Vol. 115(8), April 1978.

Fiorello, M., & Betaque, N. Aircraft system operating and support costs: Guidelines for analysis. Logistics Management Institute, Washington, D.C., February 1977.

CHAPTER 6

METHODOLOGY FOR EVALUATING HUMAN FACTORS IMPACTS IN MILITARY SYSTEMS DEVELOPMENT

The objectives of this chapter are to provide·

- A systematic framework or methodology that can be used to measure the value of human factors in the development of military systems
- A classification for different techniques or models that can be used, within the above framework, to estimate or reflect human factors related impacts on military systems.

The first section of this chapter, "Human Factors Impact Assessment: Related Concepts, Limitations, and Considerations," provides a brief overview of the underlying principles and methodologies used to formulate the recommended framework. We utilize the concepts of cost-benefit analysis and policy/impact assessment in our framework and attempt to tailor those methodologies to the human factors setting. The second section, "Human Factors Impact Assessment: Conceptual Framework," presents the set of steps that comprise the recommended methodology. Each of the steps is described, and in several of the steps a notional, human factors related problem is used as an illustration of the process. The third section, "Techniques for Estimating Impacts: Classification and Selection," discusses the step in the methodology that selects and adopts the techniques for estimating the associated costs and impacts of the human factors related recommendations in military system development. A basic classification of techniques or models is presented that can serve as a basis for identifying their characteristics, thus facilitating the selection/development of the most effective model form for the particular human factors impact under consideration.

Human Factors Impact Assessment: Related Concepts, Limitations, and Considerations

Our focus is on the assessment of human factors applications in the context of military systems development. Throughout this multi-phased development, there are opportunities for applying human factors. The major areas of emphasis of the human factors R&D products were discussed in previous chapters and listed in Exhibit 4-1. During those "windows" of opportunity, one or several human factors related actions can be considered. For each of the candidate actions, or for a set of them in which the individual actions are not separable, the quantitative and qualitative impacts must be estimated. The human factors quantitative and qualitative impacts can then be compared to the estimated impacts of other non-human factor actions (e.g., reliability growth) to assist the decisionmaker in allocating resources.

The underlying concepts used to formulate this human factors impact assessment methodology are cost-benefit analysis and system impact assessment, and their conceptual source, systems analysis.

Cost-benefit analysis is a form of systems analysis. It is a method for deriving relevant information about the desirable and undesirable effects of projects or alternative actions under consideration. The approach is, in general, analytical; it entails specifying objectives and alternative solutions and selecting the preferred alternative based upon its relative cost-benefit rating.*

*Excellent discussions on the theory of cost-benefit analysis can be found in Anderson and Settle (1977), Fisher (1971), Quade (1975), Mischin (1976), and Prest and Tuvey (1965). Quade (1975) provides a very readable overview of the evolution of systems analysis techniques, including cost-effectiveness analysis followed by cost-benefit analysis followed by impact assessment analysis.

In theory, this is just what needs to be done with respect to evaluating the contribution of human factors to system development.

A basic premise of classical cost-benefit theory is that all costs and benefits are expressed in monetary units. In many applications this requirement does not present difficulties. However, in the human factors setting the process of interpreting all the metrics and their impacts into dollars would often have to be done in an arbitrary manner, and that could distort the analysis. Presently there is no foolproof way to treat intangible, distributed impacts in a strict cost-benefit monetary forecast framework. In general, a strict cost-benefit approach for human factors analysis will not be practicable. What appears more feasible and useful is an extension of the cost-benefit approach known as impact assessment.

For these and other reasons (e.g., inability to isolate individual impacts), it may not be feasible to establish an unambiguous ordinal ranking--let alone a cardinal ranking--of the alternative actions in strictly dollar terms. What is needed is to extend the cost-benefit monetary metrics by presenting the additional relevant impacts and metrics, such as user acceptance, in their natural (non-monetary) dimensions.* Techniques such as system impact assessment do exactly that. The impact assessment matrix representation is a systematic array of the information, including non-monetary measures, and useful comparisons can be made. A simple illustration of an impact assessment matrix is shown in Exhibit 6-1. We note that in any instance in which the qualitative metrics are non-discriminatory and the quantitative metrics can be expressed in dollars, the impact assessment method reduces to the classical cost-benefit framework.

*A good introduction to system impact assessment is provided by Goeller (1976).

Exhibit 6-1

Simple Illustration of an Impact Assessment Matrix

CANDIDATE HUMAN FACTORS-RELATED ACTIONS	METRICS AND MEASURES						
	QUANTITATIVE				QUALITATIVE		
	COSTS TO DEVELOP AND IMPLEMENT ACTIONS ($)	COST SAVINGS OR AVOIDANCE ($)	SYSTEM AVAILABILITY (%)	. . .	USER ACCEPTANCE (NORMALIZED ORDINAL SCALE UNITS)	MORALE (NORMALIZED ORDINAL SCALE)	. . .
HF_1							
HF_i							

NOTE: DIMENSIONS OR UNITS OF MEASURE ARE SHOWN IN ( ).

On the other hand, where the quantitative metrics are non-discriminatory, dependence on the qualitative metrics is necessary. Where this is the case, various techniques can be used to facilitate the comparisons. One of the simplest is to use a color scoreboard approach in which the relative rankings of the candidate actions are indicated by colors for each qualitative metric or measure.* Usually four colors are used (green for best, blue for next best, red for worst, and yellow for all the others). More complex techniques assign relative weights reflecting importance to each qualitative metric or measure, utilize ordinal scales for representing the relative ranking of the actions, normalize the ordinal scales, and translate the products of the relative weights of the metrics and their normalized rankings into a quantitative rating. These and other relevant techniques that can be used to estimate the value of the metrics in the cells of the matrix in Exhibit 6-1 are discussed later in this chapter.

Methodological and Data Limitations

The impact assessment approach avoids a fundamental limitation associated with a strict cost-benefit approach. However, there are still a number of important limitations and considerations that must be dealt with when attempting to assess the potential impacts that could result from a human factors related application. These limitations and considerations are discussed next.

---

*The use of color acts as a reminder that the scale is ordinal at best, and helps prevent the natural tendency to overlook the limitations of the data. See Goeller (1976) for illustrations of this approach for transportation system decisions. The color scoreboard can easily incorporate the quantitative measures as well.

Isolating Human Factors Impacts. It is very difficult--and frequently impossible--to accurately isolate the individual impacts from aggregated impacts when the human factor impacts are not independent of one another, or when the individual contributions to the overall, aggregated impacts are not uniquely measurable.

In such instances, aggregating all the concurrent human factors related actions is called for. When the impacts from the aggregated human factor actions cannot be distinguished accurately from the impacts of the non-human factors actions, an approximate attribution of the total negative and positive impacts on the military system to the contributing actions is necessary. A conceptual basis for such attributions can be found, for example, in Saaty (1979) and Ostrofsky (1977).

Utilizing Sophisticated Techniques. Many of the models that can incorporate intangible impacts are complex, difficult to use, and not straightforward to understand. When a complex procedure is needed to assess the causal relationship(s) between an action and an impact, it will often be necessary to employ analytical specialists to apply the technique and interpret the results. The resources needed to do the analysis are part of the cost-impact assessment decisions.

Component vs. System Impacts. Often the focus of the human factors R&D activity will be on an individual procedure or component and not an entire system. When the procedure or component is changed, as a consequence of the human factors related actions, the impact should be related to the system's mission capability, cost, or compatibility. It is often difficult to relate the results of an analysis of a part to the whole. In many such instances, an opportunity cost argument for the "freed" resources or improved capability is the most appropriate explanation of the impact.

Tracking Impacts from Phase to Phase. The conceptual process envisaged calls for the consideration and assessment of human factors impacts throughout the development phases of a military system. There are officially four development phases (as per OMB Circular A-109) including milestone 3--the production decision. Each phase represents a window of opportunity for human factors related actions. The impact assessment framework is intended to be applied to the candidate actions within each phase. In keeping with the baseline concept used in cost-benefit analysis, the projected impacts are evaluated relative to a specified baseline. When a design or procedure is changed, the baseline for subsequent impact assessments is also changed. Consequently, the baseline will be continually updated as changes are introduced over the system development phases. Thus, an impact forecasted in one phase will not necessarily be additive with impacts forecasted (claimed) in earlier or subsequent phases. Impacts forecasted should be presented and documented relative to the baseline for the phase in which they are generated, and not casually aggregated across phases.

Differentiating R&D Funding Impacts. In general, it will not be apparent how to relate in a quantitative and precise manner the different R&D categories used to fund human factors analyses to differences in the resulting impacts on the system design. To the extent that the R&D budget categories and the type of R&D activity are defined and applied in a consistent manner, then a degree of differentiation will be feasible.

System vs. Non-System Specific Impacts. In general, it will not be apparent how to estimate in a rigorous way the impacts of human factors research beyond a specific weapon system setting--that is, to classes of equipment, or general military procedures. This is particularly true for "basic" research. (Note: This

problem could be an artifact of the budgeting procedures used in DOD. A distinction between human factors research (which is non-system specific) and human factors engineering (which is system specific) might remove the problem altogether.)

Data Limitations. Two recent studies, Butler (1979) and Orlansky (1979) have observed that there is a lack of sufficient homogeneous, longitudinal data to properly formulate, measure, and validate the analysis of impacts (whether human factors based or not) on military personnel performance and training. This limitation raises the issue of feasibility for any approach that requires extensive data or that does not generate, store, and measure the required data as part of its analytic design.

Risk and Uncertainty. In general, the treatment of risk and uncertainty in models that assess impacts is not adequate. Procedures do exist to quantify and incorporate risk in cost and benefit projections. See, for example, Fisher (1973), Beers (1957), Sobel (1965), Murphy (1970), and Dienemann (1966).

Manpower Policy. Analytic techniques tend to mask the military manpower policy effects on candidate design changes generated by R&D results or design variations. In general, a simulation model is required to incorporate the impact changes and manpower policy requirements in a consistent framework. Such models are often not applicable until the later stages of the system development process.

Considerations for Human Factors Practitioners

An important step in the development of a methodology is to determine the set of characteristics its potential users desire for it. We have identified three basic user requirements

that must be accommodated: compatibility with the system design process, compatibility with the human factors R&D process, and practicality of the tools.

System Design/Development Context. To be effective, the human factor impact assessment process must be compatible with the system design and development process. The methodology must facilitate the embedding of the human factors contributions and products into the system design characteristics, as described in Chapter 3, and into the system cost-performance measures.

A number of operational design tools used in cost-availability analyses (see, for example, Forster, 1974; Baran & Goclowski, 1978; Fabbro & Fiorello, 1977; and Fiorello & Betague, 1977) provide frameworks to relate system parameters, such as reliability and maintainability, to cost and performance in a causal manner. Those tools also enable the design changes under consideration to be ranked in terms of their contribution to cost reduction and/or capability enhancement. Such tools provide a useful design perspective that is relevant and necessary for the assessment of human factors R&D in system design.

In addition to the design context, the methodology must be compatible with the changing focus and characterization of the design activity, as the design progresses in its development from the conceptual through the operational stages. In the earliest stages, broad macro issues are pertinent. In the latter stages, more detailed equipment or micro issues are pertinent.

Compatibility with Human Factors R&D Issues. To be useful in the human factor R&D process, the methodology must be relevant and suitable to that process. It must utilize familiar parameters and allow for realistic interpretation of the impacts. Further,

specific tools must be capable of handling the multi-objective and multi-constraint settings typical of the human factor and manpower setting. This consideration, when fully developed into an operational screening criterion, will be useful to identify and select compatible models.

Pragmatic Procedures. In addition to being compatible with the system design/development process and the human factor R&D perspective, the methodology must also be practical to use. The trend in contemporary system analysis is to portray evaluations in as rich a formulation as possible (see Quade, 1975; and Goeller, 1976) to provide the decisionmaker with a full set of relevant information. This is done by retaining the important natural, multi-dimensional impacts and presenting them in the evaluation. The advantage of this approach is that changes to the system can be examined not only in monetary terms but also in terms of their other non-monetary impacts. The major drawback is that these procedures are becoming more and more complex, and they tend to require many explicit judgments for the various multiple impacts. Ostrofsky's (1977) design morphology is certainly a case in point, in that it provides a systematic portrayal of pertinent design issues; it can accommodate human factor parameters (through appropriate surrogates), but only at the expense of extensive detail and complex computations.

As model complexity increases, so do the skill requirements, the difficulty of interpretation, and the efforts to validate and gain acceptability for the methods.

Also, a pragmatic methodology should be flexible enough to use on a breadth of human factor related projects. It should be readily available and reasonably convenient to apply, have low

setup costs, and not require unrealistic data inputs. The intent is to develop these requirements into discrete criteria for use in the selection and application of candidate models.

Lastly, the methodology should help structure the relationship between the human factors practitioner and decisionmakers--particularly Program Managers. For example, anecdotal reports suggest that there have been incidents in which disagreements have centered on such issues as whether a design decision could be made on the basis of existing principles or some relatively informal tests, as opposed to a series of relatively elaborate experiments. A good methodology would be one which helped the parties to such divergent views reach an agreement without rancor. In other words, the methodology would be perceived by all parties of interest as providing a fair test of the time and resource investment options in a given design decision situation.

Rigor vs. Broad-Based Analysis

A fundamental issue, underlying many of the above points, is whether the analysis should be relevant, rigorous, and statistically complete, or primarily relevant (descriptive and broad). A rigorous evaluation requires (a) formal problem statements, (b) definition of the analysis and testing process within a communicable model framework, (c) the capacity for replication by different analysts at different times, (d) evaluation designs dependent upon the use or availability of baseline or control groups, and (e) that the number of observations and the number of model relationships are both greater than the number of test characteristics or variables of interest.

The notion of broad, relevant studies is used here to imply a broad-based analysis where the intent is to describe what has taken place or is expected, to identify the predominant issues

in a certain setting, and to incorporate them. Many relevant variables cannot be measured in a rigorous, quantifiable manner (for example, user acceptance and variations in skill-mix).

This dichotomy, although somewhat contrived, is pertinent to the definition of the cost-benefit or impact analyses. This is so because not all human factors issues or parameters can be analyzed in a rigorous manner. This limitation on rigorous analysis must be dealt with explicitly in a tradeoff decision during the formulation step of the analysis.

Dealing with the above limitations in itself requires management and analysis resources. It is important to recognize what the relative estimated costs are of the evaluations and the impacts. If the costs of the analyses are comparable to the expected value of the impacts, then it is likely that the analysis as defined is inappropriate.

Human Factors Impact Assessment: Conceptual Framework

Basic Framework and Steps

Exhibit 6-2 outlines the basic impact assessment framework. The development and presentation of the analysis entails ten steps or phases. The steps are presented in a logical sequence, in three groups; but in any one analysis, as indicated by the dotted lines, it may be necessary to repeat several steps in different sequences to refine perceptions and assessments of critical issues. Each step will be discussed in some detail below.

1. Establishing the Problem, Goals, and Criteria. The objective of this step is to isolate the specific issues to be analyzed, to bound the requirements, to specify the specific goals and objectives, and to derive the decision criteria.* Fisher (1971), Quade (1975), and Goeller (1976) provide useful, generic guidance for this step. Specifically, this step defines the content and purpose of the human factors product to be developed. The principal human factors products are listed in Exhibit 3-1, earlier, and Exhibit 6-6 at the end of this chapter.

This step is one that should be recognized as a variation on the generic system analysis method. The rule is: look at the ends first and work back from those ends. In human factors terminology, we would probably prefer the sequence: Goals, Objectives, and Outcome Measures (or, for the latter, Dependent Variables). However, the principle of going from the broad to the narrow and the idea of a hierarchy that includes more

*In this discussion, the term goal represents an "end," objective a "means" (that is, a specific accomplishment within an explicit time or cost target), and criteria represent specific decision conditions.

Exhibit 6-2

Impact Assessment Framework

FORMULATING THE IMPACT ANALYSIS

1. Establishing the Problem, Goals, and Criteria
2. Defining the Alternative Solutions
3. Specifying the Baseline
4. Preparing the System Definition Statement
5. Selecting the Impact Areas, Metrics, and Performance Measures

CONDUCTING THE ANALYSIS

6. Selecting/Constructing the Impact Assessment Model(s)
7. Collecting and Processing the Data
8. Setting the Conventions for the Analysis
9. Estimating and Evaluating the Impacts

PREPARING AND INTERPRETING THE RESULTS

10. Presenting the Results, Associated Uncertainties, and Bounding Conditions

"variables" as that move is made is a common link. This arrangement is illustrated in Exhibit 6-3 in a particular cost-benefit impact assessment convention (Goeller, 1976; Ostrofsky, 1977).

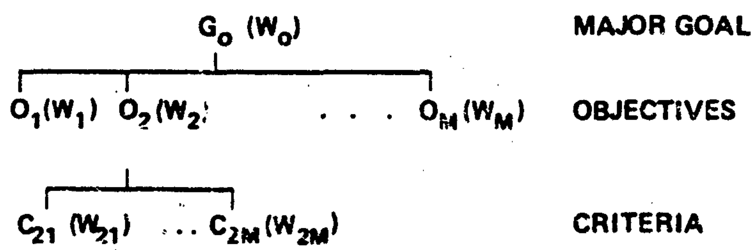
The following hypothetical example illustrates the use of goals, objectives, and weights. Assume that the system under consideration is proposed for the XYZ main battle tank. The major goal is to achieve an armored fighting unit that could defeat its hostile counterpart in certain tactical scenarios. The objective, O_1, could be that the frontal armor would hold against 80% of main round hits (i.e., any grazing angle greater than $\pm 5^{\circ}$). The objective, O_2, could be to achieve an average first-round time advantage of 3 seconds. In this case, O_2 could receive an a priori value weight somewhat higher than O_1.

Criterion C_{21} (contributing to objective O_2) could be a maximum turret traverse rate of $=>20^{\circ}$ per second. Criterion C_{22} could be a maximum elevation/depression rate of $=>45^{\circ}$ a second. In this case the criteria might be assigned equivalent value weights.

Several attributes of the hierarchical setup should now be clearer. Specifically, as one moves down the structure, the objective measurability improves. But more importantly, the actual assumptions about performance are made very explicit. That is, the design assumption clearly is that <u>if</u> a given elevation/depression rate <u>and</u> a given traverse rate are achieved, a given first round time advantage will result. Not only is that assumption measurable (e.g., by computer simulation), but the tentative weight assignment is also similarly measurable. Computer simulation would permit a whole range of permutations on the traverse rates and elevation/depression rates to be explored,

Exhibit 6-3

Goal Relevance Tree Hierarchy of
Goals - Objectives - Criteria



RELATIVE WEIGHTS:

TOTAL VALUE = W_O
OBJECTIVE WORTH = W_i
CRITERIA WORTH = W_{ij}

and a very close approximation of the relative importance of one to the other could be obtained. Moreover, the weights could be revised as other kinds of testing were done.

A notable gap in the above synthetic scenario is the lack of explicit consideration of the human factors aspects of sighting and firing the main armament. For example, human factors questions would arise about the compatibility of a maximum 80° traverse rate with the human factors requirement (hypothetical) to lock-on to a target on the first traverse with no waver. Human factors engineering solutions based on traverse deceleration rate damping, sight reticule size, etc., would need to be fitted into the goal and objective-attainment relationship as constraints. The basic message here is that it might not pay to have a relatively high traverse rate, if it led to an overswing of the turret 9 times out of 10 because the rate/velocity dynamics were incompatible with normal human (psychomotor) tracking capabilities.

The characteristics of the appropriate set of goals, objectives, and criteria is critical to the effectiveness of the analysis. Several useful discussions on this process are provided by Fisher (1971), Quade (1975), and Ostrofsky (1977). The input-output matrix technique used by Ostrofsky (1977) appears to be a particularly useful way to structure this step. An illustration of the matrix is shown in Exhibit 6-4. The row headings define the user and the system major phases, and the column headings define the requirements and bounding or constraining conditions (e.g., resources). The row headings used in Exhibit 4-1 could also be used. Ostrofsky has used this format to formally incorporate human factors considerations into the system design process.

Exhibit 6-4
Input-Output Matrix for Problem Formulation

Major System Development Phases	Inputs		Outputs	
	Intended	Environmental	Desired	Undesired
Mission Analysis				
Concept Development				
Demonstrations and Validation				
Full-Scale Development				
Production				

(Source: Ostrofsky, 1977)

The output from this step is a problem statement, an input-output matrix for bounding the design-analysis problem, and a set of weighted objectives and decision criteria to be used. The problem statement is an issue that one or more human factors related actions can help to resolve.

2. Defining the Alternative Solutions. The objective of this step is to generate a set of explicit strategies or alternative solutions to resolve the problem or issue identified in Step 1. For example, within the human factors principal R&D product--development of the role of man as a part of the mission--alternative crew sizes, mission flexibility, and system recoverability could be specific considerations. There are two major ways this can be done. The first is to specify a set of alternative design configurations or characteristics or process changes at the subsystem, component, or function level. The second is to specify a criterion function (see Ostrofsky, 1977) that incorporates the design parameters in a mathematical function, and to exercise the function to determine the preferred design or system specification. Either approach can be used. The former is more common and straightforward. The latter is typically more rigorous and requires more definitive analysis.

Making the decision options explicit is a fundamental principle of systems analysis. We can illustrate this principle in the context of using cost-benefit impact analysis to measure the impact of human factors.

Methodologies such as cost-benefit analysis are being used increasingly to support system design decisions and, to a lesser degree, to support the management decisions in system development. The application illustrated here includes both types, but emphasizes the latter. Management decisions of special interest are

those concerning <u>when</u> particular inputs to the design deliberations should be encouraged, and <u>how much</u> investment to make in each potential source of such inputs.

For illustrative purposes, then, let us say that the range of options available to the Project Manager with respect to <u>when</u> to encourage human factors inputs is given an initial framework by the four design phases previously defined, i.e.:

- Mission Analysis (MA)
- Concept Development (CD)
- System Demonstration/Validation (SD)
- Full-Scale Development (ED).

The main options, then, are:

1. None
2. MA only
3. CD only
4. SD only
5. ED only
6. MA and CD
7. MA and SD

-
-
-

16. MA and CD and SD and ED (all).

(In the higher-order options, the question of relative degree of input becomes a factor--but that factor overlaps with the allocation issue and adds a complication that is not needed for this illustration.) Thus, in this illustration there are 16 distinct alternatives for <u>when</u> human factors inputs can be encouraged. It is sufficient for this step simply to enumerate them.

3. Specifying the Baseline. The objective of this step is to define the status quo conditions relevant to the analysis; namely, the baseline. Projected impacts are evaluated in terms relative to a baseline. For each system development phase, a systems baseline must be defined. Thus, if a human factors action resulted in a design change in the demonstration/validation phase, the baseline for the succeeding system development phase would incorporate that change because it had already been accomplished. Thus, the baseline is generally tied to a phase in the development cycle.

The baseline provides a basis for the projection of future conditions in which the human factor changes under consideration are not developed and implemented. A baseline could be defined for a set of human factor impacts when the individual impacts cannot be isolated. However, it must always be defined so that the impact areas and metrics under consideration are explicitly identified.

The easiest way to understand this step is to make the argument: each new system has a (more or less direct) precursor system (or systems). The baseline rests on the precursor or composite family of precursors which we can call the reference system. In most instances, the reference system will be the one that would be used to perform the mission if the new system were not developed. For those analyses in which human factors are emphasized, the mission compatibility criterion has a strong old-new functional similarity aspect.

The following discussion illustrates the notion of the mission/functional analysis in defining the baseline. There are two analytic substeps in establishing the baseline for system design and cost projection purposes: Functional Differences and

Functional Deficiencies. The first entails the specification of the reference system similar functions and any technological differences between the reference system and the proposed new system. For example, for the XYZ tank, the reference system would be the operational MYY tank, and the technology differences that impact on the man-machine functions could include those in the main armament, armor metallurgy, turret stabilization, fire control, and propulsion components. The functions of interest are those needed to operate and maintain these components. The product from this substep is a reasonably detailed <u>functional differentiation</u>.

The second substep is a deficiency analysis of the reference system. Again, it is functional deficiencies that count. For example, was/is the reference system deficient in maneuverability? In what specific ways? We also need to know what specific human factors related deficiencies were brought to light during the field use of the reference system. Possible source data for this kind of deficiency identification could include the complaints of operators and maintenance personnel. Observations of the actual behavior of crews and maintenance units in action could also be appropriate. Also, the human factors specialist could actually go through dry runs of crucial segments of operational and/or maintenance sequences. The product from this substep is a definitive list of deficiencies. If value weights could be assigned to each deficiency in a unambiguous manner, this could also be useful.

The baseline is completed as a step in the overall methodology when the array of technological changes and reference system deficiencies are put together in such a way as to give a preliminary picture of the prospect of whether the technological changes will tend to ameliorate or accentuate the deficiencies on

a one-by-one basis. Thus from the baseline we can get a set of assumptions that indicates what some of the major design problems are going to be for the new system and, importantly, which are likely to be human factors related.

4. Preparing the System Definition Statement. The objective of the system definition statement is to summarize concisely all the essential information and assumptions about the subject system that are necessary to conduct the impact assessment. An important part of this definition is a historical record of the evolution of the system's design and development, and the corresponding impact and cost estimates. Though it will not be possible in many instances to aggregate cost-benefit/impacts from system development stage to stage, the definition statement can provide selective evidence of the role and contribution of human factors R&D.

At a minimum, the system definition statement should contain specifics on the following:

- Mission Profile (What is the system for?)
- System Performance and Operational Characteristics (What are the system capabilities?)
- Acquisition Program Schedule (How is the system to be procured?)
- Deployment (Peacetime and Wartime) Plan (How will the system be utilized?)
- Support Concept (Initial and Mature) (How will the system be supported and maintained?)
- Logistics Goals (What are the unique logistics related goals, e.g., reliability?)

- Integrated Logistics and Training Considerations (How will the operators and maintenance personnel be trained? How will the required material be purchased, managed, etc.?)
- Human Factors Related Issues (What operation and maintenance considerations can affect the cost, capability, and compatibility of the design?)

The first seven items are typically called for under current, recommended major weapon system acquisition analysis guidelines.* For these analyses, we have augmented those guidelines by adding a separate discussion of human factors related issues that should be considered. These are issues that would be noted and discussed in the human factors products (e.g., role of man) at the different system development phases. The outcome of that consideration and/or impact assessment should be reviewed throughout the system development stages.

5. Selecting the Impact Areas, Metrics, and Empirical Measures. The objective of this step is to define the system's life cycle cost, capability, and compatibility impacts, metrics, and empirical measures for the goals and criteria identified in Step 1. Some criteria may be included explicitly as cost or empirical metrics, depending on their specificity, measurability, and abstract properties.

Metrics and measures used to define the specific nature and focus of the human factors R&D impact must be tailored to the phase of system development, the human factors product form,

---

*See, for example, DOD Directive 5000.1, Major System Acquisition; 5000.39, Acquisition and Management of Integrated Logistics Support for Systems and Equipment; and DOD Instruction 5000.2, Major System Acquisition Process.

and the system-mission characterization. The impact area(s) and associated component metrics and empirical measures comprise the vocabulary to describe the effect of the human factors related change(s).

The three generic impact areas--cost, capability, and compatibility--have been introduced in previous chapters. In Chapter 5, each of the impact areas was shown to be definable in terms of a number of metrics, and the metrics were shown to be functions of combinations of empirical measures. The generic hierarchical relationship was illustrated in Exhibit 5-1. Moreover, the measures and metrics for capability and compatibility, in particular, reflect contemporary usage for describing cause-effect relationships in both human factors R&D and system engineering. In general, a human factors related change that affects capability or compatibility will also affect cost.

The set of vocabulary terms presented in Chapter 5 are from our preliminary findings. They represent an initial step toward the definition of a formal and stable set of terms to discuss, model, and communicate the effects of human factors related changes in military systems design and development. Each of the impact areas and their component metrics and measures are discussed briefly below.

- *Cost:* For a weapon system specific setting, the cost impact area is the life cycle cost of the system. A candidate set of cost metrics (major categories of costs such as Operations and Support) and measures (cost elements such as Below Depot Maintenance) were presented in Exhibit 5-5. If a military system, other than a weapon such as a C^3I system, was the subject of the analysis, it is likely that some different cost measures would be

required. The guiding criterion is: select the set of cost metrics and measures that reflects the significant, relevant costs effected by the human factors related changes.

- *Capability:* For a weapon system specific setting, the capability impact area is the mission worth of the system. A preliminary, empirically derived set of capability metrics (e.g., availability, reliability) and measures (e.g., mean-time-to-repair, mean-time-to-failure) were presented in Exhibit 5-3. The particular combination of measures used to functionally define a metric is dependent upon the system or process being analyzed, and the various ways the effect of the human factors changes can be measured.

- *Compatibility:* For a weapon system specific setting, the compatibility impact area is the physiological and psychological suitability of the design. A background discussion of compatibility metrics (e.g., user acceptance, motivation) and measures (e.g., temperature, noise, vibration stress, altitude) is given in Chapter 5. The underlying notion of the compatibility impact area is that many human factor related effects are not easily assessed using the same quantitative metrics and measures as for cost or capability. For example, reducing an operator's stress is a substantive benefit, even though its contribution to enhanced system performance is not directly quantifiable.

The result of this step is a specific set of vocabulary terms to be used for describing the impacts, and in selecting/constructing a model to estimate the values for the measures, metrics, and ultimately their effects on the impact areas.

6. Selecting/Constructing the Impact Assessment Models. The objective of this step is to derive or select appropriate techniques or models that can provide both quantitative and qualitative measures of the cost, capability, and compatibility impacts expected from the application of the human factors change.

In effect, one needs to relate the criteria from Step 1, the information from Steps 2 to 4, and the impacts and metrics from Step 5. Furthermore, that relationship must be relevant to human factors R&D products and the system development process. These relationships are tailored to and essentially define the content of the human factors efforts and cells in Exhibits 3-5 and 4-1, respectively.

A reasonable approach is to utilize Ostrofsky's (1977) design methodology as a basic procedure, and to augment it with other models that deal explicitly with life cycle cost and system capability measures. (Examples of the latter are Goclowski, 1978; Forster, 1974; Fabbro & Fiorello, 1977; AF-Logistics Support Cost Model, Design-to-Cost Model, and the Mission Success Completion Probability Model.) In addition, there are several techniques, other than Ostrofsky's, for evaluating and quantifying (imposing cardinal measures) on essentially qualitative, ordinal measures. Examples are Gardiner (1979), Saaty (1979), Quade (1975), Hays (1975), Dalky (1969), and Linstone (1975).

Briefly, the sequence envisaged is as follows (Ostrofsky, 1977):

a. For the criteria defined in Step 1, specify the underlying parameters. These parameters represent the constituents of the criteria in a systems-component sense. Each parameter is classified in terms of being:

- measured directly
- measured from a model
- included in other elements
- not measurable within existing resources.

b. Define submodels of the primitive, measurable elements to define functionally the higher-level parameters.

c. Combine the submodels into an overall model to estimate each criterion, and, in turn, an aggregate criteria function for the overall goal.

While each of these steps is critical, it is most important to understand the causal linkage between the elements, which can be a mixture of qualitative and quantitative measures, the parameter submodels, and, in turn, the criterion function. For a "hard" parameter such as reliability, the linkage between it and cost and availability is rather well understood, and many acceptable models exist. For the "soft" parameters such as user acceptance, the linkage is not nearly so clear. What is required is a procedure that will handle both quantitative and qualitative criteria (and their parameters and elements) in a systematic and credible manner.

In summary, Step 6 puts all the information from Steps 1 to 5 into a formal setting with functional, causal relationships. From the previous steps, we have:

(Step 1)

- A set of goals, objectives, and criteria in a hierarchical array.

(Step 2)

- A listing of (management) decision options.

(Step 3)

- A specification of the baseline in the form of an explicit comparison between the reference system and the proposed new system with respect to technological differences and functional deficiencies in the reference system, and projected implications of such deficiencies.

(Step 4)

- An overall characterization of the proposed new system and how it is to be operated and maintained.

(Step 5)

- A listing of critical metrics and empirical measures.

The model used to put these elements together can take a number of different forms, depending upon the system development phase and problem setting. A discussion of model types and selection criteria is given in the last section of this chapter. We can now proceed to summarize the final four steps.

7. Collecting and Processing the Data. Given the specification of the impact areas, metrics, and the model form, this step provides the required data to "drive" the model. Frequently, the lack of data in sufficient quantity or detail will constrain the nature and accuracy of the cost-benefit analysis.

8. Setting the Conventions for the Analysis. This step specifies the conventions or ground rules used in arriving at the cost, capability, and compatibility impact estimates. Conventions for cost and capability analysis should cover:

a. Normative projections

b. Constant versus adjusted dollar cost estimates/projections

c. Mature versus transient system characteristics

d. Personnel budget or economic costs

e. Capital investment leadtime considerations

f. Relevant, variable versus total costs

g. Uncertainty analysis (including technical risk)

h. Presentation and documentation standards.

9. Estimating and Evaluating the Cost Benefits. This step provides the output from the model and data prepared in Steps 7 and 8.

10. Presenting and Interpreting the Results. This step entails preparing the presentation (including illustrations and documentation of the results), identifying the requirements for additional analysis, and specifying important issues that have high degrees of uncertainty. An important part of the presentation is a description and quantitative portrayal of how the change impacted the system design and its life cycle costs and performance. Where feasible, the specific contribution of the human factors change should be isolated. Often it may not be possible to isolate the impact. In those instances, it may only be reasonable to make the comparisons at the aggregate or systems level (e.g., new vs. baseline), and to infer the role of the human factors impact. In addition to the standard tabular and

graphic presentation, the notion of color scoreboards, as used by Goeller (1976) can be used to make and present comparisons of alternatives.

Techniques for Estimating Impacts: Classification and Selection

Step 6 of the impact assessment methodology is, in some ways, the most crucial and the most complicated of the 10 steps. It involves the selection of a model (or several models) for conducting the particular analysis relative to the attributes of a given system, the human factors issues, and the phase of system development.

The selection process is complicated by the fact that there is no one model or model type that is appropriate or best for analyzing all the human factors issues throughout the system development phases. Consequently, we cannot recommend any one model for this step. Rather, we will discuss different model types and some suitable selection criteria.

Because there are a number of models that can be used in the above framework, it is useful to have, at least, a way to classify model types in terms of their basic characteristics. Our classification is a modification of the one used by Quade (1975). The model classes are not mutually exclusive; that is, a model assigned to one class can also have some of the characteristics of models in other classes. The class name indicates the basic or principal characteristics of--and the means used by--the model(s) to analyze the issues under consideration. We have identified seven model classes to catalog the types of models that are potentially useful to human factors analysis.

1. Mathematical Models
2. Computer Simulation Models
3. Experiments
4. Operational Games
5. Surveys/Group Decisions
6. Verbal Models
7. Physical Models.

A sample of some of the techniques that fall within the above classes is provided in Exhibit 6-5. As this methodology is developed and applied, additions and deletions to the sample list will be made. Of the classes of models, those used in category 1 (mathematical), category 2 (computer simulation), category 3 (experimental), and category 7 (physical) appear to be those used most frequently in human factors analysis.

A suggested set of selection criteria that can be used to identify the most suitable model to use in a given setting includes:

1. Validity (Does the model reproduce or realistically represent the functional relationships under consideration?)

2. Relevance (Does the model deal explicitly with the human factors issues under analysis?)

3. Cost (Is the model very expensive to construct or use?)

4. Non-Trivial (Does the model provide substantive insights into the process under analysis?)

5. Feasibility (Can the model be used? Are the data required available? Are the staff with the required skills available? Is there sufficient time to use the model?)

6. Reliability (Does the model give consistent results under different circumstances?)

7. Acceptability (Can the model results be communicated successfully to the system development designers and managers? Put another way, can or will the designer use the model results?)

Exhibit 6-5

Candidate Models and Techniques for Human Factors R&D Cost Benefit/Impact Assessments (sample only)

Model Category	Techniques
1. Mathematical Models The following is just a small sample of mathematical model references: See Goeller (1976), Hays, O'Connor, and Peterson (1975), Gardiner (1979), Quade (1975), Fisher (1971), Mood (1974), Petruchell (1963), Hays and Winkler (1970), Draper and Smith (1966), Baran and Goclowski (1978), Fabbro, Fiorello, and Shaw (1977), Ostrofsky (1977), Saaty (1979), Baker and Pound (1964), Cetron, Martino, and Roepcke (1967), Alboosta and Holzman (1970), Souder (1972), Fisher (1973), Martin and Sharp (1973), Beers (1957), Dienemann (1966).	Systems Analyses Techniques - Systems Impact Assessment - Policy Analysis - Sensitivity Analysis - A Fortiori Analysis Statistical (data interpretation) Techniques - Correlations (cross-section) - Regressions (simple, multiple) - Factor Analysis - Time-Series Analysis - Pooled Cross-Section Time-Series - Parametric Inferences and Projections - Multivariate Analysis Military Operations Research Models - Logistics Support Cost Model (AF-LSC) - Reliability, Maintainability, and Availability Tradeoff Models - Material Availability and Resource Investment Models Types of Design Aids - Coordinated Human Resources Technology (CHRT) Model - Life Cycle Cost Impact Model (LCCIM) - Design Morphology (Ostrofsky, 1977)

Exhibit 6-5 (Continued)

Model Category	Techniques
1. Mathematical Models (Continued)	Types of Design Aids (Continued) - Pair-Wise Comparisons - Maintenance, Reliability, Diagnostic Accuracy, - Availability, and Support Cost Models Types of Cost Models - Planning Factor Models - Detailed Engineering Estimates Decision, Risk, and Utility Theory - Decision Theory - Risk/Uncertainty Analysis - Project Scoring - Utility Scales - Relevance Tree Techniques (Reverse Factor Analysis)
2. Computer Simulation Models	Simulation-Process/Event Flow - Monte-Carlo Techniques (LCOM, CASEE, etc.) Mock-ups (analogy)
3. Experimental Methods See Davies, 1967	Types of Experiments - One-Shot Case Study (weakest but most commonly used evaluation design) - One-Group, Pre-Test/Post-Test Design (before vs. after) - The Static Group Comparison (with vs. without) - Pre-Test/Post-Test, Control Group Design (before/after and with/without)

Exhibit 6-5 (Continued)

Model Category	Techniques
3. Experimental Methods (Continued)	Types of Experiments (Continued) - Solomon Four-Group Design (controls both the experimental effect and the possible interaction effects of the measuring process itself) - Post-Test Only, Control Group Design - Comparison of Alternative Program Strategies (with random assignment) - Non-Equivalent Comparison Group - Comparison of Alternative Program Strategies - Time Series Design - Multiple Time Series Design
4. Operational Games	Gaming Techniques - War Games - Zero-Sum Games

5. Surveys/Group Decision Models
Some examples are: Dalky (1969), Linstone and Turoff (1975), Morris (1977), Brown, Cochran, and Dalky (1969).
	Nominal Group Techniques
	- Highly Structured
	- Homogeneous (e.g., only planners)
	- Small Groups (approx. 8-10)
	- Basic Steps:
	  - silent generation
	  - round robin presentation
	  - clarification
	  - voting/ranking
	  - discussion of results
	- Interpretive Structural Modeling
	- Personal Interviews

Exhibit 6-5 (Continued)

Model Category	Techniques
5. Surveys/Group Decision Models (Continued)	Nominal Group Techniques (Continued) - The Delphi Technique - structured - hierarchical - quasi-anonymity
6. Verbal Models	Scenario Building/Specification Analogy Arguments Dialectics
7. Physical Models Some examples are: Moder and Rogers (1968), Miller (1963), Conway (1967).	Types of Scheduling Aids - Program Evaluation and Review Technique (PERT) - Critical Path Models (CPM) - Functional Flow Diagrams - Graphical Evaluation Review Techniques (GERT) - Queuing Models - Programming Techniques (linear, nonlinear) Mock-ups (physical)

As we gain experience applying the above criteria and using the selected models, a more specific set of candidate techniques can be provided. Conceptually, we need to identify certain models for each of the cells in Exhibit 6-6 and indicate their applicability in terms of the selection criteria. That information could be made available in a handbook that would be updated on a regular basis.

Future Steps

The scope for this study effort includes: the development of a conceptual basis that formally relates human factors efforts and products to the major phases of a military system development, the derivation of a set of metrics that can be used to specify human factors impacts, and the formulation of a methodology to quantify the impact(s) of human factors products on the system design. This chapter accomplishes the third component (Chapter 5, the second, and Chapter 3, the first). It presents a methodology that prescribes a set of practical steps tailored to the processes of human factors assessment. Much remains to be done, however. To fully develop and understand the impact quantification process, case studies are needed to demonstrate the methodology and, especially, to select and use pertinent models (Step 6). As experience is gained, the methodology can be refined and the actual results categorized for use as future references. A useful set of references would contain: (a) a refined methodology, (b) case examples, and (c) data and models.

Exhibit 6-6

Models and Research Techniques Useful in Human Factors Analysis
in Relation to the Phases of System Development and Principal Human Factors and Products

SYSTEM DEVELOPMENT PHASE AND (↓) HUMAN FACTORS R&D PRODUCTS	CATEGORIES OF IMPACT ASSESSMENT MODELS AND TECHNIQUES						
	Mathematical Models	Simulation	Experimentation	Operational Games	Surveys And Panels	Verbal Models	Physical Models
MISSION ANALYSIS ↓ THE ROLE OF MAN							
CONCEPT DEVELOPMENT ↓ MANNED FUNCTIONS							
SYSTEMS DEMONSTRATION/VALIDATION ↓ TASK ANALYSIS AND HUMAN ENGINEERING REQUIREMENTS							
FULL-SCALE DEVELOPMENT ↓ MAN-MACHINE INTERFACE DESIGN							

References

Alboosta, C.A., & Holzman, A.G. Optimal funding of an R&D project portfolio. Presented at the 11th Institute of Management Science Meeting, Los Angeles, CA, October 1970.

Alderson, R.C., & Sproull, W.C. Requirements analysis, need forecasting, and technological planning using the Honeywell PATTERN technique. *Technological Forecasting and Social Change*, 1972.

Anderson, L.G., & Settle, R.F. *Benefit-cost analysis: A practical guide*. New York: Lexington Books, 1977.

Baker, N.R., & Pound, W.H. R&D project selection: Where we stand. *IEEE Transactions on Engineering Management*, EM-11, December 1964.

Baran, H., & Goclowski, J. LCCIM: A model for analyzing the impact of design on weapon system support requirements and LCC. Dynamics Research Corporation, 1978.

Baran, N., & Goclowski, J. Life cycle cost impact model. Technical Report R-2624, Dynamics Research Corporation, 1978.

Beers, Y. *Introduction to the theory of error* (2nd ed.). New York: Addison-Wesley, 1957.

Blalock, H.M., & Blalock, A.B. *Methodology in social research*. New York: McGraw-Hill, 1968.

Brown, B., Cochran, S., & Dalky, N. The Delphi Method II: Structure of experiments (RM-5957-PR). The Rand Corporation, Santa Monica, CA, 1969.

Brown, G. *Smoothing, forecasting and prediction*. New York: Prentice-Hall, 1963.

Butler, R. Feasibility of a cost/benefit comparison of simulators and traditional maintenance training methods (PR-105). The Assessment Group, Santa Monica, CA, 1979.

Cetron, M.J., Mostino, J., & Roepcke, L. The selection of R&D program content - Survey of quantitative methods. *IEEE Transactions on Engineering Management*, EM-14, March 1967.

Conway, W., et al. *Theory of scheduling*. Reading, MA: Addison-Wesley Publishing Company, 1967.

Dalky, N.C. The Delphi Method: An experimental study of group opinion (RM-5888-PR). The Rand Corporation, Santa Monica, CA, 1969.

Davies, L. *Design and analysis of industrial experiments.* New York: Harper Publishing Company, 1967.

Department of Defense. Major system acquisition. DOD Directive 5000.1, March 1980.

Department of Defense. Major system acquisition process. DOD Instruction 5000.2, March 1980.

Department of Defense. Acquisition and management of integrated logistics support for systems and equipment. DOD Directive 5000.39, December 1979.

Dieneman, P.F. Estimating cost uncertainty using Monte Carlo techniques (RM-4854-PR). The Rand Corporation, Santa Monica, CA, 1966.

Draper, N.R., & Smith, H. *Applied regression analysis.* New York: John Wiley & Sons, Inc., 1966.

Economic analysis and program evaluation for resource management. Army Regulation 11-18, Headquarters, Department of the Army, January 1976.

Fabbro, R., Fiorello, M., & Shaw, M. Avionics design trade-offs (working note, draft). Logistics Management Institute, Washington, D.C., October 1977.

Fiorello, M., & Betaque, N. Aircraft system operating and support costs: Guidelines for analysis (LMI Report 75-1/1). Logistics Management Institute, Washington, D.C., March 1977.

Fiorello, M., & Jaffin, S. Costs and benefits of federal automated data processing standards (DC 801). Logistics Management Institute, Washington, D.C., 1978.

Fisher, G.H. *Cost considerations in systems analysis.* New York: American Elsevier, 1971.

Fisher, G.H. The nature of uncertainty (P-5133). The Rand Corporation, November 1973.

Forster, J. Criteria for evaluating weapon system reliability, availability and cost (Task 73-11). Logistics Management Institute, Washington, D.C., March 1974.

Gardiner, P.C. Multi-attribute utility measure for logistics decision making. *Spectrum*, Summer 1979.

Goeller, B. System impact assessment (R-1446). The Rand Corporation, 1976.

Hays, L.M., O'Conner, M.F., & Peterson, C.R. An application of multi-attribute utility theory: Design to cost evaluation of the U.S. Navy's electronic warfare systems. Decisions and designs. October 1975.

Hays, W.L., & Winkler, R.L. *Statistics: Probability, inference, and decision*. New York: Holt, Reinhard and Winston, 1970.

King, G.F., & Askren, W.B. Human resources, logistics, and cost factors in weapon system development (AFHRL-TR-79-28(1)). AFSC, Texas, September 1979.

King, J.L., & Schrems, E.L. Cost-benefit analysis in information systems. *Development and Operation Computing Surveys*, 1978, *10*(1), 19-34.

Kneppreth, N.P., Hoessel, W., Gustefson, D.H., & Johnson, E.M. A strategy for selecting a worth assessment technique (DAHC19-78-G-0008). ARI-TR-280, February 1978.

Lindgren, B.W. *Statistical theory*. New York: Macmillan, 1962.

Linstone, H.Q., & Turoff, M. (Eds.). *The Delphi Method: Techniques and applications*. Reading, MA: Addison-Wesley Publishing Company, 1975.

Lockett, A.G., & Gear, A.E. Representation and analysis of multi-stage problems in R&D. *Management Science*, 1973, *19*(8).

Martin, W., & Sharp, J. Reverse factor analysis: A modification of relevance tree techniques. *Technological Forecasting and Social Change*, 1973, *4*.

Miller, R.W. *Schedule, cost and profit control with PERT*. New York: McGraw-Hill, 1963.

Mischan, E.J. *Cost-benefit analysis*. New York: Prager Publishers, 1976.

Moder, J.J., & Rodgers, E.G. Judgment estimates of the moments of PERT type distributions. *Management Science*, 1968, *15*(2).

Mood, A.M., et al. *Introduction to the theory of statistics* (3rd ed.). New York: McGraw-Hill, 1974.

Morris, K.E. The application of the Delphi technique to the development of productivity measures. Ohio State University Research Foundation, Project No. 4236-A1, Columbus, OH, 1977.

Murphy, E.I. Statistical methods of measuring uncertainty of cost estimates. Redstone Arsenal, U.S. Army Missile Command, February 1970.

Office of Management and Budget. Major system acquisitions. OMB Circular A-109, Executive Office of the President, Washington, D.C., April 1976.

Orlansky, J., & String, J. Cost-effectiveness of computer-based instruction in military training (IDA Paper P-1375). Institute for Defense Analysis, Office of the Secretary of Defense for Research Engineering, April 1979.

Ostrofsky, B. *Design planning and development methodology*. New York: Prentice-Hall, 1977.

Papoulis, A. *Probability, random variables, and stochastic process*. New York: McGraw-Hill, 1965.

Peters, R.A. Return on investment. AMACOM, American Management Association, New York, 1974.

Petruchell, R.L. Some curve-fitting fundamentals (RM-5766-SA). The Rand Corporation, Santa Monica, CA, December 1963.

Prest, A.R., & Turvey, R. Cost-benefit analysis: A survey. *The Economics Journal*, 1965, *15*(300).

Quade, E.S. *Analysis for public decisions*. New York American Elsevier, 1975.

Saaty, J. Hierarchies and priorities--Eigenvalue analysis. Draft for forthcoming publication, University of Pennsylvania, 1979.

Sobel, S. A computerized technique to express uncertainty in advanced system cost estimates. The Mitre Corporation, Bedford, MA, 1965.

Souder, W.E. Analytical effectiveness of mathematical models for R&D project selection. *Management Science*, April 1973, *18*.

Souder, W.E. A scoring methodology for assessing the suitability of management science models. *Management Science*, June 1972, *18*.

Souder, W.E. Comparative analysis of R&D investment models. *AIEE Transactions*, March 1972, *4*.

Statement, A., Bennett, W., & Moore, W. Economic analysis handbook theory and application (OAD-CR-22).
Vol. I Army Investment Analysis
Vol. II Concepts and Techniques
Vol. III Guide for Reviewers of Economic Analysis
Vol. IV Case Studies.
General Research Corporation, November 1973.

Wagner, H. *Principles of operations research.* New York: Prentice-Hall, 1969.

Wholey, J.S. Federal evaluation policy. The Urban Institute, Washington, D.C., 1975.

Wonnacott, H., & Wonnacott, R.J. *Introduction to statistics.* New York: John Wiley & Sons, Inc., 1969.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This study sets out to explore and define a conceptual basis and methodology for identifying and measuring the contributions of human factors to military system development.

Our major conclusions are:

- A conceptual basis for relating human factors contributions to system development can be defined. In Chapter 4 we identify and relate the placement and content of specific human factors efforts and products with the development phases of a military system. Each phase represents a window of opportunity for certain human factors products.

- The human factors contribution is measurable. In Chapter 5 we derive a preliminary (but useful) set of metrics for describing and measuring human factors impacts on military systems. Actually, a three-level hierarchical vocabulary is presented: systems-mission terms are at the top, for cost, capability, and compatibility impacts; metrics for defining the primary focus or results of design engineering and human factors analyses are at Level 2; and empirical measures are at the third and lowest level. We also show that system design and human factors criteria and terminology are compatible by constructing a vocabulary from engineering and human factors common and complementary terms.

- A methodology for evaluating the impacts and metrics is feasible. In Chapter 6 we build upon the basic concepts of cost-benefit analysis with recent impact assessment advances. The resulting conceptual framework can be used to evaluate both quantitative and qualitative metrics needed to represent human factors effects.

Several additional steps are required to validate these conclusions. The main step is to actually exercise the proposed methodology on some real-world cases.

In order to support such test applications, it would be most advantageous to first create two special data bases in the form of computerized relational files. One of these files should be an expanded and slightly restructured version of the file used in the present effort to establish the metrics vocabulary. The new version of this prototype file would support the elaboration and selection of the specific models (techniques) to be used in operational data collection and analysis. The other file would consist of an inventory of episodes in prior and ongoing military systems development programs (or, ideally, complete chronologies of work programs). The objective would be to provide the means to pinpoint targets for the impact assessment process.

The experience gained and results from the case study applications of the methodology should be documented in a series of Human Factors Impacts on System Development Handbooks, such as:

- Guidelines for analysis that would present:
  - the conceptual basis for relating principal human factors products and military system development phases
  - the impact assessment methodology
  - the impact assessment vocabulary.

- Models and techniques that would catalog selected models used to assess human factors related changes.

- Reference information that would present:
  - a list of the controlling documentation
  - cost and planning factors
  - description of the relational data files (discussed above).

- Issues and case studies that would document:
  - current and emerging human factors/system design problems
  - the case studies.

APPENDIX A

A RATIONALE AND PRECEDENT FOR ESTABLISHING THE PRINCIPAL HUMAN FACTORS PRODUCTS DURING SYSTEM DEVELOPMENT

The notion of principal human factors products resulting from each phase of system development is a cornerstone of the methodology developed in this report. The products of each phase were identified in Chapter 1 as follows:

MAJOR PHASE OF SYSTEM ACQUISITION	PRINCIPAL HF R&D PRODUCT
Mission Analysis Phase	– Development of the Role of Man as a part of a Mission Element Needs Statement (MENS)
Concept Development Phase	– Allocation of System Functions to Man as a part of the Decision Coordinating Paper (DCP)
Demonstration/Validation Phase	– Task Analysis and Determination of Human Engineering Requirements
Full-Scale Development Phase	– Design of the Optimal Man-Machine Interfaces

In Chapter 3, the principal human factors products were explicitly derived in terms of specific human factors efforts in each system development phase. A recommendation about the types of information included in documenting each product was also provided. The purpose of this Appendix is to provide the underlying rationale and precedent for establishing the principal human factors products in this project. Each product will be discussed separately.

Development of the Role of Man

Many approaches have been put forth for analyzing man's capabilities and limitations with respect to his potential role in system performance. Some approaches suggest that man and machines should be compared for system performance, while others suggest that man and machines are not comparable but are complementary. Some suggest that man should be designed into the system wherever possible; others suggest that man should be designed out of the system wherever possible. There are numerous controversial issues concerning man's capabilities and limitations for system performance. The philosophy expressed here (adapted from Price & Tabachnick, 1968) is (1) that man has certain unique performance capabilities that cannot be compared with machines; (2) that many system performance requirements can be obtained either by man, or man-machine design solutions (man-rated), or can be obtained by machine alone (automatic); (3) that if man's inclusion in the system is justified by his performance of mission-critical functions, his utilitarian capability may be exploited for performance of other system tasks which are not cost-effective to automate; and (4) that man has certain unique limitations which require some type of personnel support system to accommodate his physical, physiological, and psychological constraints wherever he is used. This philosophy suggests that the potential role of man in systems should be based on four questions:

1. Can man's unique capabilities be significant in the attainment of the system goals? While it is difficult to categorize man's unique capabilities, they seem to lend themselves to two major groups, as follows:

a. Man has the ability to learn; that is, acquire new knowledge and skills. Man can learn by practice, trial and error, or transfer of previous training. This unique ability to learn and transfer that learning to another situation has important implications for man's potential role in a system. First, man can perform in many complex system situations if those situations are merely similar to the learning situation; second, man can accomplish deliberate or insightful learning "on-the-job" if the occasion calls for it.

b. Man has the capacity for creative cognition. This unique capability is frequently referred to as the ability to "think," but man's truly unique characteristic is that he is capable of insightful or heuristic thinking. On this basis, it may be said that man is unique in his ability to exercise judgment in unstructured situations, or to form concepts.

2. What system performance could be implemented by man? This question is concerned with either operations or maintenance performance which is basic or clearly related to mission success, and may usually be restricted to primary or critical performance activities.

3. If a role for man is justified because of his unique capabilities (question 1) or primary performance activities (question 2), what other performance can be

assigned to him to take advantage of his utilitarian capabilities? In other words, if man is justified in the system for other reasons, then full advantage should be taken of such things as his flexibility, adaptability, and motor skills, to perform tasks which may be very difficult or costly to automate.

4. Will man's unique limitations constrain his use in the system? Together, these limitations comprise what we have been calling "compatibility" impact areas. This question must consider both system and individual factors such as the following:

   a. Man has certain physical characteristics of size, weight, shape, strength, etc.

   b. Man has physiological needs, such as air, nourishment, environmental protection, sleep, comfort, and general health maintenance.

   c. Man has psychological needs. His performance can change significantly as a result of such attitudinal variables as motivation, frustration, conflict, fear, etc.

There are at least two other key issues which should be considered in any discussion about the role of man. These are that (1) user acceptance factors are most critical and will have a maximum effect on system effectiveness as a result of the determination of man's role; and (2) determination of man's role also means a determination of whether man is local (in the

immediate mission environment) or remote (at some geographical or physical location away from the immediate mission environment).

Man's Role and Acceptance Problems

The morale of man is frequently lowered if he is not functioning at what for him is a high skill level. Aristotle defined happiness as functioning at the highest level one is capable of. More recently, Nissen (1954), in his paper on motivation, stated that "capacity is its own motivation." Consequently, if a man's system role does not permit him to exercise his capabilities or capacity, he will become frustrated and lose motivation for performing his assigned and expected system duties.

This problem of not being permitted to maintain and improve a skill capability can become compounded by an expectancy. Frequently, a man will be led to believe that he will function and learn at a higher level than in fact he will on the job. This false expectancy, often the result of overzealous recruitment, will increase the frustration due to non-use of complex skills.

Unfortunately, little work has been done on acceptance problems in complex systems. However, some work performed by Price, Smith, and Behan (1964) on acceptance problems in automated landing systems for aircraft, and the study of morale problems in the military unit, revealed the following three general principles regarding acceptance of the system role of man.

1. Men are generally accepting of system roles which give them an opportunity to exercise and, therefore, maintain skills which they feel are important to maintaining their position in the occupational and social status system in which they are immersed.

2. Men are generally accepting of system roles which permit them to vary their procedures and the manner of accomplishing their tasks, on their own initiative. Roles that fail to permit man to vary his procedures on his own are generally labeled mechanical.

3. Men are more accepting of roles which permit them to learn. In a recent study (unfortunately, utilizing a sample of only seventeen) a correlation of +.61 (statistically significant at the .01 level of confidence) was found between how much the men felt they are learning on their job and their intentions to reenlist. (pp. 70-71)

In summary, it may be said that men generally accept those roles that have more responsibility, authority, and opportunity to learn. This relates directly to the consideration of man's role in the system as local or remote.

Local or Remote Roles for Men in Systems

Military systems may be frequently conceived in terms of geographical or physical location of the performance units within the total system configuration. For the present purposes, local refers to the immediate mission environment in which the system operates, and remote refers to some geographical or physical location away from the immediate mission environment. A manned bomber, for instance, has man in a local role in the mission environment; while a ballistic missile system has man in a remote role from the immediate mission environment. Price, Smith, and Behan (1964) have also discussed this issue, particularly concerning man's local role in a system; their reasoning is included below.

> When man is included locally in a system, one of the usual reasons is to have him available to deal with unusual and unforeseen events. It is man's recognized aptitude for reprogramming or redesigning his role on the spot to deal with the unexpected that is so valuable, because it will increase system reliability. However,

this is an aptitude of man, not a subsystem output achieved at no cost to the system or system designers. Like all required outputs it is not free but requires inputs. In order to be able to effectively redesign his role, in unusual or emergency situations, two preconditions must exist, and at this point in the design we must determine if in fact they will exist. These preconditions are as follows:

a. The man must understand the over-all function of the system, and more specifically the subsystem he is interfacing with, his role in it, and how all automatic functions operate for which he might have to provide total or partial back up. Where man is not given adequate explanations as to how functions other than his own are performed, particularly machine functions, he will make up his own explanations, as has been pointed out by Firstman and Jordan (30). These explanations will more than likely be incorrect and, therefore, not an effective tool in an unforeseen situation.

b. Man must be proficient at rapidly solving new and unforeseen problems in the subsystem environment. It has been demonstrated that this capability can be learned. Such capability has been labeled <u>learning how to learn</u>, or more simply as a <u>learning set</u>. However, this ability can be created and maintained only by giving the man the responsibility and freedom to continually try out new tasks and methods. Obviously it is not possible to produce the capability in man to deal with unforeseen events by selection, traditional training methods, or job guides.

Therefore, if man is to be placed in a system, particularly locally, in order to increase system reliability by having him as an additive for dealing with unforeseen events, it is essential to give him as much responsibility and authority as is feasible. Maximum responsibility and authority are necessary to permit him to develop a learning set so that he will have the capability to deal with unexpected events. (pp. 27-28)

An interesting perspective on the local versus remote issue in the role of people and systems appeared in a recent issue (April 1978) of the *Armed Forces Journal*. Because of its brevity, the item is included below just as it appeared in the magazine.

> DON'T BE HYPNOTIZED
> BY THE FLASHING LIGHTS
>
> A senior Army leader, who has fought and won in many combat actions, raised a fundamental caution when discussing the CP advances with *AFJ*. His concern: that commanders will become so mesmerized with the fantastic display devices and torrents of information slicing into their command posts that they will stay there rather than get out with the troops fighting the battle. He says it's easy for them to convince themselves that the CP--not the fight--is the proper place for them. That is wrong, he says.
>
> He was asked how to prevent the "CP syndrom [sic]." He considers the solution fairly easy. Simply let commanders take the command post with them, by using micro-miniaturized terminals and display devices. Then they can be in the fight, but still tap the resources of the CP.

The particular item above is also of interest from the viewpoint that we are experiencing an extraordinary growth in hardware and computer technology, and this technology growth will critically impact the roles of men in future systems. It is therefore more important than ever that the human factor not become the forgotten factor at this phase of system development.

To bring this discussion of the role of man to a close, it seems reasonable to acknowledge some support of this concept from other authors. Coburn (1973), in his document entitled "Human Engineering Guide to Ship System Development," takes note of the fact that the justification for developing any new Navy system is not to produce hardware but rather to achieve some specific operational capability. Coburn further notes that these capabilities are generally the objective of the General

Operational Requirement (GOR) and that GOR 43, "Personnel Logistics," discusses human engineering. While the GOR does not use the term "man's role," it does imply a similar responsibility for human factors engineering as indicated by the excerpt included below.

> Human Factors Engineering. This area is primarily concerned with the implementation of human operator considerations in the development, operations, and maintenance of new and current organizations, weapons, and support systems. The human operator is defined in the broadest context, to include system managers, assigned leaders, operators, maintainers, and support personnel. The requirement for successful integration of people insists that qualitative and quantitative elements of normally functioning human capabilities, within the constraints of people resource availability, be the focal points around which organizations, weapons, and support systems are designed.

Air Force Regulation 800-15, Human Factors Engineering and Management, states that one of the major objectives of HFE is to assure that "man's role in the system is defined in order to optimize his performance in relation to that specific system."

Finally, Melching (1968), in a paper titled "A Concept of the Role of Man in Automated Systems," discusses the problem of man's role in highly automated Army air defense weapon systems. An excerpt of particular pertinence to the topic at hand is presented below.

> It is suggested that man's role in automated systems, although perhaps more subtle and more difficult to assess, is comparable in significance to the other factors. Thus, for example, just as the designer of a system cannot decide whether to automate a given set of functions until he is satisfied that automation is within the state of the art, so should he not attempt to assign functions to man until he has arrived at a satisfactory conception of the general role of man in that system.

In other words, to guide him in this thinking and planning, the designer of an automated system needs a clear-cut conception of the general role of man in such systems. Without this basic guidance, the functions that he allocates to man may reflect only a sort of "fallout" from his attempts at automation, rather than any careful premeditation on his part. In short, the designer needs a conception of what man's role *should* be before he can decide what it *will* be.

In brief summary, it is the opinion of the present authors that determination of man's role during the mission analysis phase of the systems development is a key human factors product upon which hinges the critical impact of human factors with respect to capability, cost, and compatibility.

The Allocation of System Functions to Man

In every military system development cycle there must be decisions concerning (1) if man should be in the system or not, and (2) if he is in the system, what he will do. If one is concerned with obtaining optimal human performance in military systems, then clearly, determining (1) whether man will have a role, and (2) if so, what functions he will participate in are two of the most important decisions in a system development cycle that bear upon this concern. Subsequent activities in system development that are concerned with task analysis, selection, training, and human engineering of interfaces for man in the system are consequences of the role and allocation of function decisions and cannot make up for bad decisions in these two areas.

Despite the importance of these two decision steps concerning man's performance in the system to be developed, there has been a general concern in the literature and among human factors professionals that allocation of function decisions is inadequate. This is not a new concern.

In a document entitled "Factors Affecting Degree of Automation in Test and Checkout Equipment," which, among other things, reviews the problems of allocation of function, Swain and Wohl (1961) assert:

> A rather stark conclusion emerges: There is no adequate systematic methodology in existence for allocating functions (in this case, test and checkout functions) between man and machine. This lack, in fact, is probably the central problem in human factors engineering today . . . It is interesting to note that ten years of research and applications experience have failed to bring us closer to our goal than did the landmark article by Fitts in 1951 (p. 9).

In an article entitled "Allocation of Functions Between Man and Machines in Automated Systems," Jordan (1963) discusses current problems and efforts to allocate functions between men and machines, and arrives at a similar conclusion to that of Swain and Wohl. Jordan's final conclusion is stated as follows: "Herein lies the main future challenge to human factors engineering." (p. 165)

Jordan also presents an analogy drawn from the physical sciences and concerned with the concept of "ether," which:

> . . . played a central role in physical thinking for over a century after having first been introduced as a necessary medium for propagating electromagnetic waves. But during all this time all attempts to build and expand upon this concept led to difficulties and contradictions. A century of research on ether turned out to be sterile in that no significant advance was made during that time.

The conclusion which Jordan draws from this analogy is as follows:

> The lesson to be learned from this momentous episode is that when a scientific discipline finds itself in a dead end, despite hard and diligent work, the

> dead end should probably not be attributed to a lack of knowledge of facts, but to the use of faulty concepts which do not enable the discipline to order the facts properly. The failure of human factor engineering to advance in the area of allocation of functions seems to be such a situation . . . .

During studies of highly automated Army Air Defense Systems, Melching (1968) arrived at a similar concern over the allocation of functions in systems, as indicated below.

> With the aid of extremely capable electronic computers, such systems are able to process vast amounts of environmental and other data. The capability of these systems is such that they can, at least theoretically, conduct an entire battle without the assistance of man.
>
> Such a prospect is awesome, to say the least. As a consequence, the builders and users of such systems have shown a strong inclination to design them so that a manual override of some sort is possible. No one, it seems, is willing to let the machine make all the decisions.
>
> Manual override, however, is only one of several issues that tend to arise in connection with highly automated systems. Numerous other questions also appear. For example, in what specific ways and in what circumstances would man be justified in intervening in the actions and decisions of an automated system? Should man ever be given duties other than that of system override? Should man ever function in series with the machine component? Or should he function only in a parallel backup fashion?
>
> All these questions, of course, are expressions of a problem that has long plagued system designers--that of allocation of functions between man and machine.

Men and machines are not competitors. This statement is paramount when one is concerned with the allocation of a system function for performance by a man or a machine. <u>It is equally poor system design to have a man doing a machine's job or a machine doing a man's job</u>.

Many system or function performance requirements may be implemented by solutions involving man as part of the design concept. Such solutions, wherein it is feasible to use man as part of the solution, are called man-rated (from Price & Tabachnick, 1968). Thus, man-rated performance is any performance that can be obtained with man as part of the design solution. The essential question of function allocation is what functions are man-rated and what is the most advantageous extent of man's participation.

The range of human participation in potential man-rated solutions may actually be a continuum; however, for the sake of simplicity only the ends of the continuum need be defined. These two points are simply called manual and automatic.

Manual performance implies that a man performs the function; that he generates or accomplishes whatever power, energy, or energy transduction is required; and, furthermore, that he controls the application of power or directs the utilization of the given energy. No assumptions are made about the nature of the activity. It may utilize human receptors or effectors, or both. The definition does not preclude the use of tools (e.g., a chart, a lever, or a telescope) which merely extend man's raw capabilities.

Automatic performance implies that a machine performs the function by generating or accomplishing whatever power, energy, or energy transduction is required; and that a man controls, in real time, the application of the power or directs the utilization of the given energy. In automatic function performance man participates, but indirectly. He may determine what is to be done, and perhaps how, as in the use of a digital or analog computer. He usually monitors the output to determine whether it meets certain minimal performance standards. He initiates and may terminate the operation of the automatic device, as in the use of an autopilot.

As may be seen from the discussion above, the problem of allocation of functions to men in many cases becomes a decision as to the degree of automation. The decision to automate a function in many cases makes the role of man qualitatively more demanding. Recent advances in the state of the art in engineering and computers have produced machines with tremendous capacities and speeds which may require fewer personnel to operate, but which also may place increasingly more difficult tasks on those personnel who must install, maintain, monitor, override, and program these systems. If the task complexity of personnel performances in a highly automated system is to be reduced to the point where highly skilled personnel are not required (or at least reduced), then the burden of responsibility lies with the human engineering of the interface between the automatic machine and the human monitor or operator. In this way, training costs and time for personnel can be kept to a minimum. The general advantages of the automated system apply to the extremes of any performance continuum. For example, monitoring functions which either do not change over long periods of time, or change extremely rapidly in time, are best performed automatically. Those monitoring functions that are in the middle of the continuum may well fall within the capabilities of a human monitor and be performed by man with as much reliability and accuracy as by the machines, and at much less cost.

Finally, a special consideration that needs to be pursued in allocating functions is user acceptance. Recent advances in computer technology have presented a temptation to system designers to automate functions whenever possible. This may create more problems than it solves, particularly with respect to the compatibility impact and user acceptance.

Acceptance problems could be defined as any frustration of any human needs. As an example, excessive automation, particularly in information processing systems, may end up overloading the

user with more information than he can handle. Excessive automation may also restrict man from performing at his highest skill level. If automation does not permit man to exercise his capabilities or capacity, he will become frustrated and lose motivation for performing his assigned and expected system functions. Problems created by lack of confidence in the effective and reliable performance by hardware of automated functions must be considered independently of whether in fact the hardware is effective and reliable. If man does not accept a particular automated function, he simply will not perform in the manner that the system designer intended.

What is needed is the development of an awareness of the need for considering user attitudes when system design decisions are being made. This will permit the incorporation of acceptance factors as one criterion in tradeoff analyses that already include a consideration of the performance capabilities and reliabilities of man and equipment components. It may be found, for example, that a decision to automate a particular function based upon sound engineering considerations would produce a degree of negative acceptance that would clearly offset the anticipated advantages of the engineering solution. Price, Smith, and Behan (1964), in the study of pilot acceptance of automated landing systems, offer the following principles as guidance concerning automation acceptance.

1. The more system experience a man has, with this experience including exposure to automated equipment, the more accepting he is of the automated equipment and the more he will use it in the prescribed manner.

2. Those with more status, responsibility, and authority tend to be more accepting of and make more use of automated equipment than others.

3. Where failure of the performance of its function by automated equipment can endanger the life of the man, he is less likely to accept and use it despite prescribed procedures.

4. There is generally high acceptance, within the limits of the above three principles, of the automation of servo tasks, particularly those which must be performed over long periods of time.

5. There is generally rather low acceptance of automation of decision making functions.

In concluding this discussion, it is salient to note that the allocation of system functions to man (or machine) is recognized as a human factors product by DOD and all three services.

DOD recognizes the definition and allocation of function in MIL-H-46855B, Human Engineering Requirements for Military Systems, Equipment and Facilities.

The Army recognizes function allocation in AR 602-1, Human Factors Engineering Program, and in HEL Guide 1-69, Manpower Resources Integration Guide for Army Material Development.

The Navy recognizes function allocation in NAVMATINST 3900.9, Human Factors; in the Human Engineering Guide to Ship System Development (Coburn, 1973); and a report on Human Factors Engineering for Navy Weapon System Acquisition (Baker et al., 1979).

The Air Force recognizes function allocation (man-machine analyses) in AFR-800-15, Human Factors Engineering and Management; and in AFSC Design Handbook 1-3, Human Factors Engineering.

Task Analysis and Determination of
Human Engineering Requirements

As suggested by the title, this human factors product has two parts. The first part, Task Analysis, is a delineation of the specific task performance (both operator and maintenance) required to be performed by man. The second part, Human Factors Engineering Requirements, is more concerned with how man is expected to accomplish those tasks (at least some of them will be aided by human engineering), and the identification of information and response requirements (interfaces) between man and the system. Human factors personnel should provide (1) both the methodology for and performance of task analysis, (2) the identification of human engineering as a means of achieving (or assisting) task performance, and (3) specific requirements or techniques for man to receive information from the system and to make responses to the system.

Task Analysis Requirement

Task analysis has been employed by those individuals concerned with the "Personnel Subsystem" ever since people have been recognized as an integral part of military systems. Task analysis as it is generally practiced today was probably first formalized by Miller (1953). It is the basis for human engineering because it is necessary to know "what" is expected of people in systems before we can prescribe "how" personnel are to achieve what is expected of them.

Task analysis data is clearly required by MIL-H-46855B, Human Engineering Requirements for Military Systems, Equipment and Facilities. Also, the Tri-Service Advisory Group for Human Factors is developing a new task analysis requirement.

The need for task analysis to support training and performance aids has also been recognized by DOD and the services and was recently summarized (at least for maintenance) by Foley (1978) in a report on the impact of advanced maintenance data and task oriented training technologies on maintenance, personnel, and training systems.

Human Factors Engineering Requirements

Achieving Personnel Performance. As stated earlier, once it has been determined "what" people will do in systems it is necessary to determine "how" to provide for achievement of the expected performance.

There are, in general, four ways in which one may develop personnel performance achievement:

1. Personnel selection
2. Training
3. Job aids and manuals
4. Human engineering.

Personnel selection techniques are useful when a small number of personnel are required, highly specialized skills are required, extensive experience is required, system personnel are to assist in system development, and the system is essentially a one-shot attempt.

Training is a valuable (but expensive) technique when all of the performance requirements can be specified, a relatively large number of system personnel will be involved, system personnel will be a permanent or semi-permanent complement, skill requirements are relatively high but not specialized, and extensive experience is not required.

Performance aids and manuals will always be required in military systems. However, performance aids are particularly valuable in cases where there is relatively high personnel turnover, skill requirements are relatively low, task performance can be specified in detail, and large numbers of system personnel are involved.

Human factors engineering is also a means of achieving (or assisting in achieving) personnel performance, as well as reducing error probability. A system which provides sufficient and meaningful information to the human operator or maintainer and provides adequate and compatible methods for responding to system demands can substitute for selection, training, and performance aids in some cases. Furthermore, human engineering becomes a permanent part of the system and the investment is usually made once, whereas the investment in training must be made over and over as personnel turnover occurs. Moreover, human engineering applied throughout a large complex system can make training (and cross-training) easier, and can make it easier for both a novice and an experienced individual to operate or maintain the system. Thus, a significant human factors activity is to determine what types of human performance can best be achieved or assisted by human engineering.

No matter what the primary method for achieving human performance is, human engineering will affect the reliability with which man can perform his intended role, functions, and tasks whenever he must interface with the system. Data need to be available to system designers with respect to enhancing human reliability through enhancing both the behavioral and attitudinal interface between man and the system--the compatibility factor.

Human Information and Response Requirements. Finally, as part of the human factors engineering product a determination should be made of information and response requirements necessary

for the user to interface with the system. The terms information and response are deliberately used in place of displays and controls since the actual selection or design of displays and controls should occur after it is known what information and response will be required of the system user. This will permit consideration of combining information on a single display or time-sharing the display or similar considerations which are only possible after all of the information requirements are known. The same thing is true for response requirements and the eventual design of controls.

The human may receive information either from the environment directly or through displays of the machine; he may also make responses directly to the environment or to the machine through its controls. In an operating system, all inputs either to the man or machine may be considered system demands. All outputs from the man or machine may be considered system performance.

A final observation should be made that the man and machine inevitably operate in some kind of environment. This could be a physical environment, such as the roadway or the atmosphere; and it could be an organizational environment such as an aircrew, communications network, or a management information processing function. No matter what the context of the environment, it imposes demands on the man-machine system, which in turn responds to provide system performance in the operating environment.

Design of Optimal Man-Machine Interface

An optimal man-machine interface design is that which is the most desirable from the human factors viewpoint while remaining within the constraints of the overall system design. This human factors product probably needs the least explanation and the least justification for being included as part of the system and

equipment design decisions during the Full-Scale Development Phase. It is during this phase that design decisions will result in hardware, software, and procedures with which people in systems must interact. These design decisions and their compatibility with the human physically, behaviorally, and attitudinally are the loci for human errors in system performance. While not all human errors are disastrous with respect to system performance, certainly no one would argue that human error must be minimized, particularly when this can be done at minimum cost before hardware, software, and procedures are released for production. The answer simply lies in having available data and expertise which will be a part of design decisions concerning man-machine interfaces in the Full-Scale Development Phase.

MIL-STD-1472B is, of course, a fundamental requirement of complex systems under development and provides the basis for the design of optimal man-machine interfaces. There are many other widely accepted handbooks or guidebooks which provide information, primarily about man's physical and behavioral characteristics, that must be accounted for. However, even at this level of system design it is still essential to consider the attitudinal variables.

Through training and experience man has built up many habit patterns that lead him to expect things to look, sound, or feel a certain way. Conversely, there is a psychological phenomenon known as perceptual constancy which allows us to perceive certain things for what they are, even though they are distorted or symbolic. This has relevance in the design of the equipment interface, as certain types of instrument symbols are more acceptable than others because they meet man's perceptual expectancy or do not exceed his bounds of perceptual constancy. A practical example of this is the symbolic representation of

the runways as part of a head-up display--some representations are simply more acceptable than others.

This completes the discussion of the four principal products of human factors R&D. It is the opinion of the authors that there is ample rationale and precedent for the establishment of these products as an integrated part of system development.

References

Armed Forces Journal International. Don't be hypnotized by the flashing lights. Vol. 115(8), April 1978.

Baker, C.C., Johnson, J.H., Malone, M.T., & Malone, T.B. Human factors engineering for Navy weapon system acquisition. Naval Sea Systems Command, Washington, D.C., July 1979.

Coburn, R. *Human engineering guide to ship system development: Responsibilities, procedures, and methods for carrying out human engineering programs.* NELC/TD 278. San Diego, CA: Naval Electronics Laboratory Center, October 1973.

Department of the Air Force. Human factors engineering. AFSC Design Handbook 1-3. Headquarters, Air Force System Command, Andrews AFB, Maryland, January 1977.

Department of the Air Force. Human factors engineering and management. AF Regulation 800-15. Headquarters, U.S. Air Force, Washington, D.C., October 1974.

Department of the Army. Human factors engineering program. AR 602-1. Headquarters, Department of the Army, Washington, D.C., June 1976.

Department of Defense. Human engineering requirements for military systems, equipment, and facilities. MIL-N-46855B. January 1979.

Department of Defense. Human engineering design criteria for military systems, equipment and facilities. MIL-STD-1472B. May 1978.

Department of the Navy. Human factors. NAVMATINST 3900.9. Headquarters, Naval Material Command, September 1970.

Foley, J.P. Impact of advanced maintenance data and task oriented training technologies on maintenance, personnel, and training systems. AFHRL-TR-78-25. Advanced Systems Division, Air Force Human Resources Laboratory, WPAFB, Ohio, September 1978.

Jordan, N. The allocation of functions between man and machines in automated systems. *Journal of Applied Psychology.* June 1963.

Melching, W.H. A concept of the role of man in automated systems. HumRRO Professional Paper -14-68. Human Resources Research Office, May 1968.

Miller, R.B. A method for man-machine task analysis. Report No. WADC-TR-53-136. Wright Air Development Center, WPAFB, Ohio, June 1953.

Nissen, H.W. The nature of drive as innate determinant of behavioral organization. In Jones, M.R. (Ed.), Nebraska Symposium on Motivation, 1954. University of Nebraska, Lincoln, NB, 1954.

Price, H.E., Smith, E.E., & Behan, R.A. Utilization of acceptance data in a descriptive model for determining man's role in a system. NASA CR-95. National Aeronautics and Space Administration, Washington, D.C., 1964.

Price, H.E., & Tabachnick, B.J. A descriptive model for determining optimal human performance in a system. Vol. III: An approach for determining the optimal role of man and allocation of function in an aerospace system (including technical appendices). NASA Ames Research Center, Moffett Field, CA, March 1968.

Swain, A.D., & Wohl, J.G. Factors affecting degree of automation in test and checkout equipment. Dunlap and Associates, Inc., Stamford, CT, 1961.

U.S. Army Engineering Laboratory. Manpower resources integration guide for Army materiel development. HEL Guide 1-69. Aberdeen Proving Ground, Maryland, 30 January 1969.

APPENDIX B

DERIVED VOCABULARY LIST OF HUMAN FACTORS METRICS

System-Related Terms and Associated Dimensions (Unit of Measure)

ACCESSIBILITY	subjective: satisfactory/unsatisfactory ease of admission to various areas of an item
ACCURACY	probability/frequency of documented error
CAPABILITY	subjective: mission objective achievable given the condition during the mission
COMPATIBILITY	subjective: ability of items of equipment to coexist (including effect of temperature and moisture
CRITICALITY	subjective: relative degree of task importance for mission success
DURABILITY	probability: item will survive a) its projected life b) overhaul point c) rebuild point without a durability failure (failure that causes an item to be rebuilt or replaced)
EASE OF USE	subjective: tasks associated with simplicity, readability, etc.
FAILURE RATE/FREQUENCY	1) number of failed items 2) number of effects (out of tolerances) per month, week, hour, etc.
FIRING RATE	time (measured from firing to reloading of weapon)
HABITABILITY	subjective: adequacy/ease of space, transport, watch standing, rest, relaxation, workspace and access
MALFUNCTION, SYSTEM INITIATED	frequency per unit time (hours) based on available reliability data & maintenance data
MEAN FLIGHT HOURS BETWEEN MAINTENANCE ACTION	mean probable flight hours between maintenance actions
MEAN-MAINTENANCE TIME	1) mean hours preventive and corrective maintenance 2) total preventive and corrective maintenance time divided by total number of preventive and corrective actions during a specified interval
(MTBAMA) MEAN TIME BETWEEN ANY MAINTENANCE ACTION	same as MTBF except all maintenance actions are collected as data

(MTBF) MEAN TIME BETWEEN FAILURE	1) mean time a system functions until occurrence of a failure requires corrective maintenance (characteristically over a two-month period) 2) total functioning life of a population of items divided by the total number of failures within the population during a measurements cycle (time, cycles, miles, events, etc.)
(MTBM) MEAN TIME BETWEEN MAINTENANCE	mean of the distribution of time intervals between maintenance actions
(MTBUMA) MEAN TIME BETWEEN UNSCHEDULED MAINTENANCE ACTION	same as above except only unscheduled maintenance is collected as data
(MTTR) MEAN TIME TO REPAIR	total corrective maintenance time divided by total number of corrective maintenance actions during a specified interval
($MTTR_A$) MEAN TIME TO REPAIR (ACTUALLY ACHIEVED)	total corrective and preventive maintenance time divided by total number of corrective and preventive maintenance actions during a specified interval
($MTTR_F$) MEAN TIME TO REPAIR (FLIGHTLINE)	mean probable time spent in flightline maintenance before system is returned to a ready-for-operation condition
($MTTR_I$) MEAN TIME TO REPAIR (INHERENT)	total corrective maintenance time divided by total number of corrective maintenance actions during a specified interval
($MTTR_O$) MEAN TIME TO REPAIR (OPERATIONAL)	total corrective maintenance time divided by total number of corrective, preventive, administrative, and support maintenance actions during a specified interval
(OPERATIONAL) SUITABILITY	subjective: 1) establishment of system operability in operational environment (within stated constraints) 2) identification of adequate instrumentation, comfort, visibility, handling, etc. of systems by personnel
(PILOT) WORKLOAD	subjective: degree of effort required to accomplish a specific task
PRODUCIBILITY	(T&E application): subjective ability of differences between prototype and production models to achieve desirable result (as a result of ECP & program change orders)
READY RATE, OPERATIONAL	% of assigned items capable of performing an assigned mission or function

SAFETY	1) probability of injury or damage 2) subjective: satisfactory/unsatisfactory materials, fire & explosion protection, mechanical & electrical hazards)
SERVICEABILITY	time: ability to service in specified interval
STANDARDIZATION/ COMMONALITY OF DESIGN	degree of similarity (lack of ambiguities) of two displays designed to same specifications and standards
SUBSYSTEM EFFECTIVENESS	subjective: the technical capability of a subsystem (RADAR, FLIR, etc...) to accomplish a specific task
SURVIVABILITY	probability that a system will withstand hostile man-made environment and retain mission accomplishment capability
TIME, DOWN (DOWN TIME)	time (hours, frequency, duration) which an item is not in condition to perform its specified function
TRANSPORTABILITY	subjective: ease of transit, packaging, load/ unloading, security & fastening
WEAROUT	rate of increase in failure rate of items over system life (cycles, time, miles)

Personnel-Related Terms and Associated Dimensions (Unit of Measure)

ACCIDENT RATE	number per specified number of hours
ACCURACY	1) kill/no kill ratio 2) % correct 3) subjective: associated with cognitive skills (e.g., observing, estimating, detecting, recognizing, positioning, reading, etc...) 4) measure of precision and/or timeliness of performance
ANXIETY	subjective: stress factors associated with pilots (e.g., training, confidence)
APTITUDE AND SKILL	1) testing scores (e.g., AFQT) 2) subjective: low vs. high
ATTRITION/TURNOVER	% attrition—number of attrited personnel divided by number of attrited personnel plus number of non-attrited personnel
DISSATISFACTIONS/ SATISFACTIONS	subjective: ratings of challenge, personnel-job match, perceived degree of utilization
EFFICIENCY	rating success on a task
ERROR RATE (ANALYSIS)	1) mean error per performance time 2) percent and/or number of operator error (e.g., forgetting, accidents, inability, etc...) 3) analysis: includes a) amplitude b) frequency c) type d) change over time
ILLUMINATION LEVEL	1) measure: luminance 2) subjective: number of lighting deficiencies
INJURY	subjective: injury type, severity, frequency
MAINTENANCE, CORRECTIVE	number, rate, frequency of acts performed to restore an item to a specified condition
MAINTENANCE, PREVENTIVE	number, rate, frequency of actions performed to retain an item in a specified condition
MALFUNCTION, HUMAN INITIATED	frequency of test participant (operator) error resulting in system/item malfunction
(MOBA) MILITARY OPERATIONS IN BUILT-UP AREAS	1) communications distance (limitations) 2) weapons effectiveness 3) tactics effectiveness

MORALE	subjective: ratings of individual personnel identification and satisfaction with work group, job activities, duties, supervision, etc.
MOTIVATION	subjective: rating of desire to perform duties, obtain experience, advance
NIGHT OPERATIONS	performance (target identification) in night missions
NOISE/BLAST	sound pressure measurements (e.g., dbs, amplitude, also velocity, wavelength frequency in herz)
PERFORMANCE TIME OR RATE	mean time/number per some unit/rate
PRODUCTIVITY	units produced per some interval
PROFICIENCY	test scores (written)
RADIATION	radiation effects aircrew performance on radiation environments
REACTION TIME	1) (time reaction): uptime to initiate a mission, measured from the time the command is received 2) operator perception time (or start time) in response to some initiating stimulus
STRENGTH	amount lifted (kilograms)
STRESS, GENERAL	gas (general adaptation syndrome)
STRESS, TASK OVERLOAD	subjective: workload excessiveness
TASK COMPLEXITY/ DIFFICULTY	subjective: rating based on knowledge and skill required for performance
TASK DURATION	total time required for task completion (also as in tracking targets-% of time on target)
TASK FREQUENCY	number of responses made by an operator(s) in a specified interval
TEMPERATURE	measures of comfort and performance in variable temperatures
TIME, ADJUSTMENT/ CALIBRATION	time required to make needed response
TIME, CHECKOUT	time required to verify performance of an item (in specified condition)
TIME, FAULT CORRECTION	time required to correct a failure
TIME, FAULT (ISOLATION) LOCATION	time (hours) measured from discovery of a fault/ failure to correct identification of failed item

TIME, TASK TIME	time required to perform task
TIME, TURNAROUND	time required to service or check out an item for recommitment
USER ACCEPTANCE	subjective: underuse, misuse, abuse of equipment due to dissatisfaction with: a) machine function b) status c) economic fears d) survival fears e) enjoyment of manual performance of tasks
VAPORS/EMISSIONS	measured in parts per million (PPM) over specified time
VIBRATION	frequency (in Hz) over a unit exposure time
WINDFORCE (Q-FORCE)	windspeed indicator (impact on physical operating environment)
WORKLOAD	subjective level of effort required to accomplish a task

APPENDIX C

EXAMPLES OF HUMAN FACTORS EFFORTS RELATED TO SYSTEM DEVELOPMENT PRODUCTS AND METRICS

Application of the Metrics Approach to the Evaluation of Human Factors Products

Previous chapters have demonstrated that human factors products are explicitly tied to the formal sequence of military system development, and that the stages represent a progression from the general to the specific. It should also be remembered that each human factors product exists in order to provide a response to a generic problem in system development.

The mode of illustration in this section will be to fill in some of the cells of the matrix in Exhibit C-1 with specific metrics. The intent is to demonstrate that these assignments can be made in a sensible manner. In several cases, we will also go a further step and show how empirical measures fit into the metric level. Again, the objective is demonstration, not an exhaustive explication.

Supplementary Evaluation Considerations

An important aspect in the evaluation of the human factors contribution to military system development should be the quality of the human factors products; that is their "intrinsic" merits. An example is a human factors report that is assessed on its overall relevance or cogency, the logic of the derivation of its conclusions, the validity of the data used in the inferential reasoning presented, and even its readability.

Our more structured approach is not intended to preclude such a mode of assessment. Indeed, that kind of evaluation

Exhibit C-1

Illustrations of Metrics Used to Link Human Factors Products and Impact Areas

Impact Areas	Human Factors Products			
	Determination of Human Role	Allocation of Functions	Task Analysis and HE Requirements	Man-Machine Interface Design
Cost	Cost Associated with Depot Maintenance	Cost Effectiveness of Design Modifications	Cost Savings Through Human Factors Simulator Device Usage	Cost Savings Through Increased Use of Operator Population
Compatibility	Motivation (User Acceptance)	Operability	Performance (Effectiveness)	Design/Production (Producibility)
Capability	Performance (Readiness)	Skill Task/Workload Performance	Maintainability	Performance

is virtually spontaneous. We would expect all human factors products to be evaluated in that more judgmental mode. Such judgmental evaluations are useful and needed but they do not go far enough. Specifically, a report such as is mentioned above could be entirely cogent and valid and still not be valuable to the system designers. Certainly they would not perceive it as valuable unless the recommendations were seen to make a positive difference in the cost, capability or compatibility of the system. To do so requires the linkage with their concepts of system impact areas--"caste," in their (the designer's and system development manager's) terminology.

Metrics and Principal Human Factors Products

Human Role x Cost. We have filled-in the cell in the upper left hand corner of the matrix with the metric of cost associated with depot maintenance, as shown in Exhibit C-1. The rationale for this example is that the human role in the maintenance process is implicitly or explicitly defined when the system maintenance philosophy is promulgated early in the design process. A typical parameter at this level is the threshold of the choice of repairing a subassembly at the operational unit or replacing it. If the philosophy is to replace most subassemblies, the function of repair and the cost associated with that repair work becomes a depot responsibility. The human factor aspect would be the extent to which quick and accurate fault diagnosis could be performed at the operations unit level. That outcome, in turn, would be influenced by the quality of available test equipment and job aids for operational unit level maintenance technicians.

Given some actual data on these parameters plus a consideration of the complexity of the system, spare parts availability, etc., and an accurate characterization of the fault diagnosis performance

of maintenance technicians in similar situations, the human factors recommendation might be to work toward the circuit-card level of replacement as opposed to the subassembly level. If such a recommendation were valid, it could lower maintenance costs and could link across to such metrics as system availability in the sense that time-to-repair could be reduced.

Allocation of Functions x Cost. An example is shown in which the metric cost associated with a design modification to a radio device is cast in terms of allocated functions between men and machine (represented by the cell at the intersection of the Allocation of Function Column and the Cost row). Modern technology is not prone to simple devices and a "black box" fix can often add to, rather than alleviate user problems. For example, the automatic tuner for the AN/GRC-19--a high frequency, AM, medium power radio--turned out to be more trouble than it was worth. Development commenced in the early years of World War II and the set was fielded in 1949. Prior to the AN/GRC-19, standard radio sets required the operator physically to change the length of the antennae and to go through a series of "dipping" and "peaking" operations to tune the transmitter to the operating frequency. A well-skilled operator was required to get the most out of the radio, and training such operators was not easy. The designers of the AN/GRC-19 sought to eliminate this training problem by incorporating a "black box", an automatic tuning assembly which was expected to substantially decrease requirements for operator training, as well as increasing the speed and accuracy of tuning. The AN/GRC-19 passed its acceptance tests and was put into use. But over the years (last procurement was 1965), the Army experienced a net loss in system cost-effectiveness. While the transmitter tuned more rapidly, the operator needed as much training to manipulate the "black box" as the former manual system demanded, and the training of maintenance personnel had to be increased to

take care of the tuner. The following data reveal the cost and other associated effects upon the cost-effectiveness of having an automatic tuner added to the AN/GRC-19 radio.

Cost	+25%
Size and Weight	+15%
Repair Costs	+10%
Speed of Tuning	Improved
Operator Training	Same
Maintainer Training	Increased

In sum, the Army bought rapid tuning at a substantial price in higher procurement, shipping, maintenance and training costs. Had the cost-effectiveness of the machine-allocated function been compared with the original man-allocated version (as was done retrospectively in the data summarized above), the designers would have seen no utility in the design modification. (Portions adapted from TRADOC Pam 71-8)

Task Analysis and Human Engineering Requirements x Cost. Cost savings are anticipated through increased development and use of simulators for training and skills maintenance, especially in the areas of maintenance and flight training. Simulators have been touted as capable of reducing or eliminating a need for operational systems and/or spare parts, since all necessary functions (e.g., malfunctions) are simulated. In addition, with increasing costs associated with flight training and air skills maintenance due to energy resource consumption, simulators offer an economical alternative means for skill development and retention. Especially desirable is the maintenance of combat readiness for pilots in Air Combat Maneuvering (ACM). The practice required to reach optimal readiness levels places high cost factors upon actual aircraft and fuel resources. Use of simulators offers an

opportunity to escape heavy costs and achieve desirable readiness states. Maintenance trainers such as that developed for the Heads-up Display tester associated with the A-6E aircraft offer an attractive $700,000 savings per copy.

In order to safeguard huge investments in simulator R&D, much human factors (HF) R&D has been invested to: 1) determine characteristics relevant to critical performance in the operational environment which must be simulated (through task analysis and human engineering), and 2) verify the effectiveness of simulators developed from such research. While the advent of the age of simulators presents HF R&D with a unique opportunity for empirical simulator research, the cost-effectiveness of such research must be demonstrated through actual improvements in skill proficiency and readiness. While cost savings postulated through a one-for-one substitution of simulators for actual systems results in an obvious numerical cost figure, no accounting is made of training and readiness losses or gains made through the substitution. Perhaps more called for is a detailed cost-effectiveness modeling approach which takes into account such benefits as: reduced training time, training experience with rare or hard-to-duplicate events or contingencies, better monitoring of student performance by instructors, etc. It is understood that recognition gained through simulator usage will of necessity be shared with the simulator design and training communities, but nonetheless human factors claims a co-equal share of the responsibilities and benefits. Cost savings demonstrated through the use of simulators will to a great extent vindicate human factors input and investment in this technology.

Man-Machine Interface Design x Cost. Cost savings demonstrated through an increase in the number of personnel made available to operate a system can be a powerful metric for demonstrating the

underlying value of the HF R&D that led to the savings. A computer modeling procedure, the crewstation assessment of reach model, was developed to simulate operators in aircraft cockpits so as to determine, among other things, the percentage of the pilot population which could safely operate controls as well as be safely accommodated by cockpit size and arrangements. This model is used to "step-through" various cockpit design configurations, with the intent of evaluating the man-machine match, before the aircraft and its cockpit are actually built. Use of this model has increased the percentage of aviators available for such aircraft as the F-18. This has resulted in the achievement of subst...ial cost savings in terms of manpower alone, variously described as being between $5 and $40 million a year. In addition, other long term cost savings may be achieved, such as those associated with reduction in aircraft accidents, possible redesign/retrofit of aircraft cockpit configurations, and the availability of a new design evaluation tool for use by industry on a continuous basis. Whatever the actual cost savings achieved (and a detailed cost-benefit model may more fully exploit this), the cost of the HF R&D has been fully exceeded by received benefits to the system as well as reduced costs.

Human Role x Compatibility. Had human motivation been considered a vital metric in measures of system performance at the time when large multiple man-machine systems (e.g., SAGE) first evolved from manual to automated operations, user acceptance would have readily been seen as a primary component of motivation leading to mission effectiveness. User acceptance by implication is heavily compounded with job satisfaction. For jobs to be satisfying three conditions seem to be necessary: the system must demand the operator to use skills; the job must be meaningful; and the operator must perceive real responsibility in job performance. In designing and thinking about our new complex

automated man-machine systems we must learn to design for men jobs that are intrinsically interesting and satisfying.

A researcher who was involved with the SAGE program makes the following comparisons:

> One notices a striking difference when comparing the behavior of the crews in the old manual Air Defense Command sites to the crews in the SAGE direction centres. In the manual site almost every crew member took pride in his job. I had occasion to visit many of them, and in every site the crew members to whom I talked would eagerly go to great trouble to explain to me the intricacies of their job and what it demanded of them for good performance. A comparable pride and eagerness was almost completely lacking in the SAGE direction centres I visited. Men just cannot be proud of something which bores them.
>
> If we look closely at the job demands in a SAGE direction centre, we find several striking differences between it and the manual sites it replaced. First, for most jobs, skill requirements have been reduced to a bare minimum. Second, most of the jobs have become so isolated and fractionated that they have become meaningless in terms of the overall crew mission responsibility. One clear-cut example of this isolation and fractionation will here be given; there are many others.
>
> Most of the jobs in an air defense system involve relaying information; i.e., information is processed or acted upon and then relayed to another position for further processing and action. Each job by itself, although clearly defined, generally has little meaning when the total picture of crew's actions are lacking. In the manual sites there was a central plotting board which showed such a picture for all the crew members to see. No such summarizing display is available for a member of a SAGE crew.
>
> Third and last, because of the fantastic performance ability of the computer, because of the inflexibility of even the most so-called flexible program, and because of the mystery, to the crew members, of what goes on inside the computer, and reinforced by the effect of the preceding two conditions, the roles of

> the human operator in SAGE and the computer have functionally been reversed. Rather than the machine being an aid to the man, the man becomes an aid to the machine. In addition to boredom generated by the reduction of skill, there is a feeling of futility generated by the feeling of having lost control over what is going on. Maybe this is all we desire of the men in our emerging complex automated man-machine systems, that they merely be aids to the machine, but it is legitimate to raise the question whether this desire is itself desirable.
>
> In designing complex systems, regardless of our good intentions, we can often create a situation that becomes intolerable for the human being, and as a result he either leaves the system or, if he cannot, he subordinates himself to the system and ceases to play the role which is the ultimate role of men in man-machine systems, *to see to it that the system works.*

(from Jordan, 1968).

As was made explicit in the preceding discussion, not only should the Role of Man be considered early in system development to include elements of motivation, personnel satisfaction, and user acceptance; but by direct extension a case can be made for systematic development of measures such as user acceptance and metrics such as motivation to document HF R&D improvements in systems. Improvements in user acceptance not only benefit man as a user, but must also ultimately pay off in improvements to overall system performance as well. This may especially be the case for emergency and contingency situations in automated systems (e.g., SAGE).

<u>Allocation of Function x Compatibility</u>. The metric chosen to demonstrate the linkage in this case is operability. The allocation "problem" is dramatically illustrated by the case of automated (computerized) landing systems. Such systems may not be operable because they violate human factors principles with respect to user acceptance. Specifically, it has been feasible

for several years to control carrier landings by computers used in conjunction with some advanced radar telemetry devices. In spite of their demonstrable accuracy, such systems are not cost-effective because the pilots disengage or under-use them.

All such systems have a manual override feature, for obvious reasons. Pilots exercise the override feature even when the system is working perfectly because they cannot bring themselves to invest their trust in a system in which a "slight" malfunction could cost their life or career. From the pilot's point of view, the advantage is not worth the potential cost/risk associated with a malfunction--particularly if the system might be susceptible to nonobtrusive malfunctions.

Test data could show that the probability of a mishap or a missed approach is significantly reduced by the automatic system. Thus, from an engineering viewpoint the pilot is wrong. However, from an outside functional point of view, the system is inoperable and might as well not be on board.

The empirical measure in this case could have been a survey of pilot attitudes. Had this been done and a human factors report been produced when the allocation-of-function decisions were being made, a system might have been designed that would have been compatible with pilot attitudes, operable, and thus effective. Note that this case also links back to cost considerations. In effect, all the development costs of this system were lost when it became apparent that the system was inoperable.

<u>Task Analysis and Human Engineering Requirements x Compatibility</u>. The metrics chosen to demonstrate the linkage between task analysis and human engineering requirements and compatibility are: performance and effectiveness. The Army has shown compatibility factors (e.g., crew turbulence) which have

clear effects upon mission success, armor weapon accuracy, speed of use, as well as overall crew cohesiveness. Identification of pertinent design factors at the task analytic and human engineering requirements levels would serve to mitigate some of the user problems seen in the field. The U.S. Army has long been concerned with getting the maximum capabilities and effectiveness out of its armor weapon systems. Much of the capability of any weapon system is a function of the performance of the crewmen assigned. Some people in the armor community have expressed concern that crew turbulence--the movement of crewmen from crew to crew and position to position--may have a negative impact on tank system effectiveness. Research conducted during recent years has addressed this notion and attempted to identify the relationship between tank crew turbulence and tank crew performance.

Tank crews contain four crewmen, a tank commander--commonly called a "TC,"--a gunner, a driver, and a loader. For the tank weapon system to achieve full potential, each must perform effectively in his assigned position. Each duty position within the tank system requires unique skills and smooth coordination with the other crew members. The TC must identify and range on targets, communicate his findings to the gunner and loader, and be prepared to guide the driver through difficult terrain based solely on voice commands. The gunner's response to the TC's identification of a target must be coordinated with the loader's response to the TC's command specifying the type of ammunition to be loaded. The accurate synchronization of these duties is essential.

Three types of turbulence were identified. They were: equipment, personnel, and position turbulence. Equipment turbulence occurs when a crew is moved from one tank to another. Personnel turbulence occurs when crewmen are moved from one crew

to another, but kept in their positions. And position turbulence occurs when crewmen are moved from one position to another. Assignment changes which create personnel and position turbulence are always accompanied by equipment turbulence. From the data, it appeared that position turbulence had a significant degrading effect on gunnery performance. However, for equipment and personnel turbulence, little or no effect was indicated. All types of turbulence could be minimized if it were possible to assign each crewman to a permanent position, tank, and crew upon his arrival in the unit. However, this ideal procedure is often not feasible, because a sufficient number of trained TC and gunner replacements are not always available to fill vacated positions. Consequently, units must fill TC and gunner positions from available crewman. To cope with the turbulence required by the assignment system, a unit may frequently move crew members up within crews, where possible, or between crews where necessary. These problems with crew turbulence which have direct effects on metrics of performance and effectiveness are an example of compatibility issues which need to be brought before equipment design engineers. Human factors personnel need to identify design recommendations which achieve desirable levels of standardization across crews' positions in order to facilitate (among other things) cross-training and thus reduce the negative aspects of crew turbulence.
(Portions from Eaton and Black, 1980).

Man-Machine Interface x Compatibility. To demonstrate this linkage we have chosen a particularly challenging example: the evaluation of the product of detailed design by the impact area of compatibility using the producibility metric. This assignment is again illustrated in Exhibit C-1. The challenge can be met by the consideration of the human factors aspect of the production process itself. What we are saying here is that the detailed

design must be compatible with the attributes of the workers who will fabricate the system. Of all the possible linkages between human factors product, metric, and impact area, this is one of the more likely to get "swept under the rug" in the development process. However, the logic is not that complicated. For example, at the design recommendation level in the layout of an instrument panel, the procedure can involve a design review against standard industrial fabrication practices that asks the question: Is there any aspect of the fabrication of this panel that will require deviation from standard practices? If the answer is yes, the next question is: Does the nonstandard requirement generate a possible mismatch between what must be accomplished and the physiological, behavioral, or attitudinal attributes of the production workers? Specifically, are parts involved that are so small that positioning is difficult for individuals with normal vision and normal dexterity? Does fabrication involve the assembly of pieces by touch because the worker cannot observe the back of the panel after a particular production stage has been reached?

In short, the human factors products at the detailed design level should incorporate not only a recommendation that will lead to an effective interface between the human operator of the system and the control panel, but should also include a consideration of the compatibility of the design with the tools, practices, and attributes of the humans who will put the control panel together.

As indicated, the main impact can be designated as compatibility but, again, it should be noted that a good design in this instance would have effects in the cost area, and probably other metrics as well.

Human Role x Capability. Automated Battlefield Systems are being developed at a rate which may surpass the ability of HF R&D to offer input to each in sufficient quantity. The Army alone is procuring approximately 60 new automated tactical systems in the coming decade. Role-of-man decisions--made explicitly or implicitly by design engineers--will have a great influence not only on human performance capabilities and limitations but also on overall system and mission capability. To make matters more critical, automated systems have had a history of problems related to man's role, complexity, as well as system hardware and software architecture.

As much as comprehensive HF R&D is required to take advantage of opportunities offered by the use of automated technology, with the problems just mentioned, a method to assess the impact of human factors on the course of development for these systems is also necessary. For example, systems-embedded training within fielded tactical systems offers a rare opportunity for training operators to readiness states required for successful mission completion in actual combat environments. The opportunity for HF R&D to aid in the refinement of embedded training is limited only by the resources available to fund it. HF R&D may be invested in: software developments for "canned" scenarios and training packages, guaranteeing the realistic nature of the training such as to mimic the expected operational environment by displaying representative data to system operation; as well as other areas of concern. Measures of personnel and system readiness as well as proficiency, productivity (in terms of task data utilized), and performance time or rate may be used to evaluate the effectiveness of the embedded training to successfully train operators, and to evaluate skills acquisition and maintenance by operators undergoing training; they also provide the capability to verify the value of HF R&D that was invested in the effort. This component may then be aggregated with others to

form metrics such as readiness, performance, etc. Finally, through an analysis of type found in the model described in Chapter 6, metrics may be merged to assess the impact upon system capability. Given that the information was available on the example cited, systems-embedded training, as well as other relevant data (e.g., compatibility of the man-machine integration, feelings of lack of responsibility and detachment from system performance, effectiveness of manual override as well as others for each alternative configuration of a system), a strong case could be demonstrated for the value of HF R&D in battlefield information systems development.

Allocation of Functions x Capability. That the allocation of functions between men and machines is dependent upon the role assigned man is nowhere as clearly demonstrated as when man is remotely located in the system. Remote location of man in the system eliminates direct observation and control of system functions. Also, by implication, remote system monitoring requires heavy dependence upon automation and communication links. Needless to say, manual override is totally surrendered to the system, at least as regards that portion from which the man is remotely located.

Since military intelligence requirements consist, at least in part, of locating enemy troops, and identifying concentrations and types (infantry, armor, vehicle, etc.), the military saw fit to meet this requirement by engaging in development of Remotely Piloted Vehicles (RPVs). RPVs function to scout the enemy in the battlefield, gathering intelligence data about them through the use of drone aircraft (the RPV) that carry video sensors. Of course, by design the human is remotely located in the system. Once the location of man in the system is designated to be remote, man's role would be limited to only those possibilities available

under such circumstances. Decisions regarding the allocation of functions to men and machine will be based on this human role decision, with all its advantages and disadvantages. Therefore, the mission success of the RPV surveillance depends on the ability of human operators to (a) detect significant information from video displays, (b) ignore "noise" or non-significant video display information, and (c) distinguish friendly from enemy forces. It is up to HF R&D at this point to ensure positive effects upon system capability.

Allocation of functions within human performance capabilities and limitations becomes a critical concern of system developers. Care must be shown in designating man-rated functions which are within available human performance capabilities and skill levels, as well as other more basic concerns such as perception and decision making. Measures of accuracy-in-vigilance type tasks of the sort to be encountered in actual operation of the system would be useful in determining human performance capabilities, as well as task complexity/difficulty. HF R&D may also aid in selecting aptitude and skill requirements for RPV operators through measures such as proficiency.

These measures, along with others which represent quantifiable measures of capability, may be aggregated together in a model such as that presented in Chapter 6 to form metrics such as general skills, performance, and task/workload. These metrics may then be utilized to determine the impact on capability as a result of this HF R&D investment.

<u>Task Analysis and Human Engineering Requirements x Capability</u>. This cell is filled-in in Exhibit C-1 with the metric "maintainability." The mode of approach is to show that the product in this case can be evaluated by measuring that product against maintainability criteria that link to the capability of the system.

Design-for-maintainability is a well established concept in the development of military systems. In this particular instance, we can look at something as simple as the design of access hatches for re-arming combat aircraft. From an aerodynamics point of view, such hatches must be flush and faired so that the fasteners and handles do not spoil the air flow in flight. Consequently, there may be a temptation on the part of the designer to overlook the fact that the speed with which these hatches can be removed could be crucial to the combat effectiveness of the system. Similarly, it can be optimal from a human factors point of view that removal and replacement be accomplished using conventional tools, and that the geometry of the fasteners and the complete hatch be such that it precludes errors such as mispositioning the hatch upon replacement or not properly locking the fasteners.

The product, in this case, would be a hatch cover design that would meet both the requirement for good aerodynamics and the requirements for quick and easy access and error-free hatch cover replacement. The evaluation at the empirical level would be speed and accuracy of performance during re-arm operations in a prototype test situation. A more comprehensive evaluation would be one that would reveal the consequences of reduced turnaround time on the overall mission effectiveness of the system. This level of outcome can, indeed, be estimated by impact analysis techniques discussed in Chapter 6.

<u>Man-Machine Interface Design x Capability</u>. Increased accuracy in airborne weapons use has been a continuous goal of researchers for obvious reasons. As in so many instances, weapons accuracy is highly dependent upon a compatible man-machine integration. One effort has been to improve the target acquisition side of weapon systems (as opposed to the purely engineering side,

which involves just machine capability). The primary element of target acquisition of necessity involves a human performance component. That component has become more critical in today's airborne threat environment, which has increased in lethality as well as requiring aircraft to be upgraded in continuously high flight regimes (speed) at the edge of the aircraft's flight envelope. This has resulted in a military requirement to aid the human operator in target acquisition. Addressing the human component in target acquisition has resulted in refinement of television (TV) and forward-looking infrared (FLIR) systems. These systems were designed to improve identification and recognition of potential targets, actual target acquisition and, finally, the probability of achieving a kill. A critical element in the viability of such systems is human performance capabilities associated with perception. HF R&D was required in order to determine the density of scan lines necessary for optimal target acquisition performance in one such system. This R&D contributed to the overall capability potential of the weapon system in the following areas:

- Increased weapon accuracy resulting in higher kill ratios
- Reduced acquisition time
  - correlated with increased probability of achieving a kill
  - reduced vulnerability.

Taken as measures of performance, these areas may be aggregated into a performance metric which may also contribute to effectiveness and system survivability. A model tailored to evaluate the contribution of this HF R&D to capability added to target acquisition performance and the overall system could clearly demonstrate that the HF R&D was instrumental to this system development effort.

Summary

As shown above, it is possible to identify a set of metrics that are demonstrably acceptable to design engineers (because they are extracted from engineering documentation), and that also serve to relate the empirical and analytical measures used by human factors specialists. This circumstance encourages the view that the human factors products that enter (or should enter) into the military system development process can be evaluated in strictly engineering terms.

Several cases were described that tend to verify that view. What is still lacking is a comprehensive and orderly methodology for collecting the appropriate data and generating explicit, quantitative conclusions about the specific value of a particular human factors product for a particular military system development effort.

References

Department of the Army. Analyzing training effectiveness. TRADOC Pam 71-8. Headquarters, U.S. Army Training and Doctrine Command, Fort Monroe, VA, February 1976.

Eaton, N., & Black, B. Tank crew turbulence. *Army Research, Development and Acquisition Magazine*, *21*(2), March-April 1980, p. 10-12.

Jordan, N. *Themes in speculative psychology*. London: Tavistock Publications, 1968.

DISTRIBUTION

1 US ARMY WESTERN COMMAND ATTN: APPE
1 HQDA ATTN: DAAG-ED
1 HQ, ICATA ATTN: ATCAT-OP-Q
2 HQDA RESEARCH AND STUDIES OFC
1 MILITARY OCCUPATIONAL DEVELOPMENT DIV DAPC-MSP-O, RM 852C HOFFMAN BLDG 1
4 OASD (MRA AND L)
1 HQDA ATTN: DAMO-RQR
1 HQ TCATA TECHNICAL LIBRARY
1 HQDA ODCSPER
1 USRADCO, STC
1 HQDA ATTN: DAMI-ISI
1 USA AVIATION SYSTEMS COMD ATTN: DRSAV-ZDR
1 USA CORADCOM ATTN: AMSEL-PA-RH
1 USA ARRADCOM ATTN: ATFE-LO-AC
1 HEADQUARTERS, US MARINE CORPS ATTN: CODE MPI-20
2 US ARMY EUROPE AND SEVENTH ARMY
1 1ST INFANTRY DIVISION AND FT. RILEY ATTN: AFZN-DPT-T
1 USA INTELLIGENCE AND SECURITY COMMAND ATTN: IAOPS-TNG-T
2 HQ TRADOC TECHNICAL LIBRARY
1 NAVAL TRAINING EQUIPMENT CEN ATTN: TECHNICAL LIBRARY
1 MILITARY OCCUPATIONAL DEVELOPMENT DIRECTORATE ATTN: ATZI-NCR-MS-M, RM 3N33 HOFFMAN BLDG II
1 DATA ANALYSIS DIVISION ATTN: ATZI-NCR-MD, HOFFMAN BLDG II
1 USA MILPERCEN ATTN: DAPC-POO-T
1 USAFACFA CHIEF, ORGANIZATIONAL EFFECTIVENESS BRANCH
1 8TH INFANTRY DIVISION
1 HQDA ARMY FORCE MODERNIZATION COORDINATION OFFICE
1 NAVAL AIR SYSTEM COMMAND /
1 DCSOPS (DIST 4) ATTN: DAMO-RQT
1 123D USARCOM RESERVE CENTER
1 US ARMY SOLDIER SUPPORT CENTER ATTN: ATSG-HDD (DR. CAVINESS)
1 DIRECTORATE OF ARMOR AVIATION ATTN: ATZK-AAD
1 USAARMC + FT. KNOX AVIATION DIVISION
1 USA FORCES COMMAND AFIN - DEPUTY C OF S FOR INTELLIGENCE
1 USA FORCES COMMAND AFOP - DEPUTY CHIEF OF STAFF FOR OPERATIONS
1 US ARMY AIR DEFENSE SCHOOL ATTN: ATSA-DTD
1 DIRECTORATE OF TRAINING ATTN: ATZQ-T
1 DIRECTORATE OF COMBAT DEVELOPMENTS ATTN: ATZQ-D
1 HQDARCOM MARINE CORPS LIAISON OFC
1 DEPARTMENT OF THE ARMY US ARMY INTELLIGENCE + SECURITY COMMAND
1 US ARMY SAFETY CENTER ATTN: LIBRARIAN, BLDG 4905
1 USA MISSILE COMMAND ATTN: DRSMI-NTN
1 ARTADS ATTN: DRCPM-TDS-TD
1 USA FORCES COMMAND
1 PM TRADE /
1 US MILITARY DISTRICT OF WASHINGTON OFC OF EQUAL OPPORTUNITY
1 NAVAL CIVILIAN PERSONNEL COMD SOUTHERN FLD DIV
22 ARI LIAISON OFFICE
1 7TH ARMY TRAINING COMMAND
1 HQ USAREUR ATTN: DCSOPS
1 HQDA, OCS STUDY OFFICE
1 U.S. NAVY TRAINING ANALYSIS EVALUATION GROUP
1 USACDEC ATTN: ATEC-EX-E HUMAN FACTORS
1 USAF, GOS/TAC SENIOR ARMY ADVISOR
1 INTER-UNIV SEMINAR ON ARMED FORCES + SOC
1 USA ELECTRONIC PROVING GROUND ATTN: STEEP-MT-ES
1 OASA (RDA) DEPUTY FOR SCIENCE AND TECHNOLOGY
1 OFC OF NAVAL RESEARCH /
1 AFHRL/LRT
1 AFHRL/LRLG
1 AIR FORCE HUMAN RESOURCES LAB ATTN: AFHRL/TSR
1 FEDERAL AVIATION ADMINISTRATION CENTRAL REGION LIBRARY, ACE-66

1 AFAMRL/BB
1 AFAMRL/HE
1 NAVAL PERSONNEL R AND D CENTER COMMAND AND SUPPORT SYSTEMS
1 NAVY PERSONNEL R AND D CENTER /
1 NAVY PERSONNEL R AND D CENTER DIRECTOR OF PROGRAMS
1 NAVY PERSONNEL R AND D CENTER /
1 US ARMY AVN ENGINEERING FLIGHT ACTIVITY ATTN: DAVTE-TD
2 OFC OF NAVAL RESEARCH PERSONNEL AND TRAINING RESEARCH PROGRAMS
1 NAVAL PERSONNEL R + D CENTER /
1 OFC OF NAVAL RESEARCH PROJECT OFFICER, ENVIRONMENTAL PHYSIOLOGY
1 DEPT. OF NATIONAL DEFENCE DEFENCE AND CIVIL INSTITUTE OF ENVIR MED
1 NAVAL AEROSPACE MEDICAL RSCH LAB AEROSPACE PSYCHOLOGY DEPARTMENT
1 USA TRADOC SYSTEMS ANALYSIS ACTIVITY ATTN: ATAA-TCA
1 HEADQUARTERS, COAST GUARD CHIEF, PSYCHOLOGICAL RSCH BR
1 USA RESEARCH AND TECHNOLOGY LAB ATTN: DAVDL-AS (DR. R. S. DUNN)
1 USA ENGINEER TOPOGRAPHIC LABS ATTN: ETL-GSL
1 USA ENGINEER TOPOGRAPHIC LABS ATTN: STINFO CENTER
1 USA ENGINEER TOPOGRAPHIC LABS ATTN: ETL-TD-S
1 USA MOBILITY EQUIPMENT R AND D COMD ATTN: DRDME-TQ (SCHOOL)
1 NIGHT VISION LAB ATTN: DRSEL-NV-SDD
1 USA TRAINING BOARD ATTN: ATTG-ATB-TA
1 USA HUMAN ENGINEERING LAB
1 USAHEL LIAISON REP, USAAVNC /
1 USA MATERIEL SYSTEMS ANALYSIS ACTIVITY ATTN: DRXSY-C
1 USA RESEARCH OFC /
1 NAFEC HUMAN ENGINEERING BRANCH
1 BATTELLE-COLUMBUS LABORATORIES TACTICAL TECHNICAL OFC
1 USA ARCTIC TEST CEN ATTN: AMSTE-PL-TS
1 USA COLD REGIONS TEST CEN ATTN: STECR-OP
1 USA CONCEPTS ANALYSIS AGCY ATTN: CSCA-RQP
1 USA CONCEPTS ANALYSIS AGCY ATTN: CSCA-JF
1 HQ WRAIR DIV OF NEUROPSYCHIATRY
1 USACACDA ATTN: ATZL-CAC-IC
1 USACACDA ATTN: ATZL-CAC-IM
1 USACAC ATTN: ATZL-CAC-IA
1 USACACDA ATTN: ATZL-CAC-A
1 USA ELECTRONIC WARFARE LAB CHIEF, INTELLIGENCE MATER DEVEL + SUPP OFF
1 USA RSCH DEVEL + STANDARDIZA GP, U.K.
1 AFWAL/FIGR (CDIC)
1 USA RESEARCH AND DEVELOPMENT LABS CHIEF, BEHAV SCIENCES DIV, FOOD SCI LAB
1 TRAJANA ATTN: SAJS-OR
1 NAVAL AIR SYSTEMS COMMAND ATTN: AIR-5313
1 ECOM ATTN: AMSEL-CT-O
1 USACDEC TECHNICAL INFORMATION CENTER
1 USAARL LIBRARY
1 HUMAN RESOURCES RSCH ORG (HUMRRO) /
1 SEVILLE RESEARCH CORPORATION
1 USA TRADOC SYSTEMS ANALYSIS ACTIVITY ATTN: ATAA-SL (TECH LIBRARY)
1 UNIFORMED SERVICES UNIT OF THE HEALTH SCI DEPARTMENT OF PSYCHIATRY
1 USA COMPUTER SYSTEMS COMMAND ATTN: COMMAND TECHNICAL LIBRARY H-9
1 HUMAN RESOURCES RSCH ORG (HUMRRO)
1 HUMRRO LIBRARY
1 EUSTIS DIRECTORATE, USAAMRDL TECHNICAL LIBRARY
1 RAND CORPORATION /
1 RAND CORPORATION ATTN: LIBRARY D
1 FEDERAL AVIATION ADMINISTRATION ATTN: CAMI LIBRARY ACC-44D1
1 NAFEC LIBRARY, ANA-64
1 GRONINGER LIBRARY ATTN: ATZF-RS-L BLDG 1313
1 CENTER FOR NAVAL ANALYSIS
1 NAVAL HEALTH RSCH CEN LIBRARY
1 NAVAL ELECTRONICS LAB ATTN: RESEARCH LIBRARY
1 NAVAL PERSONNEL R AND D CEN LIBRARY ATTN: CODE P106

1 AIR FORCE HUMAN RESOURCES LAB ATTN: AFHRL/OTS
1 HQ, FT. HUACHUCA ATTN: TECH REF DIV
1 USA ACADEMY OF HEALTH SCIENCES STIMSON LIBRARY (DOCUMENTS)
1 SCHOOL OF SYSTEMS AND LOGISTICS /
1 USAMERDC TECHNICAL LIBRARY
1 DEPARTMENT OF THE NAVY TRAINING ANALYSIS AND EVALUATION GP
1 NATIONAL CENTER FOR HEALTH STATISTICS /
1 USMA DEPT OF BEHAVIORAL SCI AND LEADERSHIP
1 OLD DOMINION UNIVERSITY PERFORMANCE ASSESSMENT LABORATORY
1 USA COMMAND AND GENERAL STAFF COLLEGE ATTN: LIBRARY
1 USA TRANSPORTATION SCHOOL USA TRANSP TECH INFO AND RSCH CEN
1 NASA HQ /
1 NMRDC PROGRAM MANAGER FOR HUMAN PERFORMANCE
1 NAVAL MEDICAL R AND D COMMAND (44)
1 USA ADMINCEN TECHNICAL RESEARCH BRANCH LIBRARY
2 HQDA USA MED RSCH AND DEVEL COMMAND
1 USA FIELD ARTY BD /
1 NAT CLEARINGHOUSE FOR MENTAL HEALTH INFO PARKLAWN BLDG
1 U OF TEXAS CEN FOR COMMUNICATION RSCH
1 INSTITUTE FOR DEFENSE ANALYSES
1 USA TRAINING SUPPORT CENTER ATTN: ATIC-DST-PA
1 AFHRL TECHNOLOGY OFC (H)
1 PURDUE UNIV DEPT OF PSYCHOLOGICAL SCIENCES
1 USA MOBILITY EQUIPMENT R AND D COMMAND ATTN: DRDME-ZG
1 HQ, USA MDW ATTN: ANPE-OE
1 DA US ARMY RETRAINING BDE RESEARCH + EVALUATION DIVISION
1 CALSPAN HUMAN FACTORS AND TRAINING CENTER
1 USA AEROMEDICAL RESEARCH LAB SCIENTIFIC INFORMATION CENTER
1 USAF SCHOOL OF AEROSPACE MEDICINE AEROMEDICAL LIBRARY (TSK-4)
1 US MILITARY ACADEMY DEPT. OF HISTORY, BLDG 601
1 USA INTELLIGENCE CEN AND SCH ATTN: SCHOOL LIBRARY
1 USA INTELLIGENCE CEN AND SCH ATTN: ATSI-DT-DL
1 MARINE CORPS INSTITUTE
1 NAVAL SAFETY CENTER /
1 USAAVNC AND FT. RUCKER ATTN: ATZQ-ES
1 US ARMY AVN TNG LIBRARY ATTN: CHIEF LIBRARIAN
1 USAAVNC ATTN: ATZQ-D
1 US MILITARY ACADEMY DIRECTOR OF INSTITUTIONAL RSCH
1 USA AIR DEFENSE SCHOOL ATTN: ATSA-CD-MS
1 USAADS-LIBRARY-DOCUMENTS
1 USA AIR DEFENSE BOARD ATTN: FILES REPOSITORY
1 USA INFANTRY BOARD ATTN: ATZB-IB-AE
1 USA INTELLIGENCE CEN AND SCH ATTN: ATSI-DOTD-SF
1 USA ORDNANCE CEN AND SCH ATTN: ATSL-TD-TAC
1 USA ARMOR SCHOOL ATTN: ATZK-TD
1 USA ARMOR CENTER DIRECTORATE OF COMBAT DEVELOPMENTS
1 NAVAL POSTGRADUATE SCH ATTN: DUDLEY KNOX LIBRARY (CODE 1424)
1 USA TRANSPORTATION SCHOOL DEPUTY ASST. COMMANDANT EDUCA. TECHNOLOGY
1 USA SIGNAL SCHOOL AND FT. GORDON ATTN: ATZH-ET
1 USA ARMOR CENTER + FT. KNOX OFFICE OF ARMOR FORCE MGT + STANDARDIZATION
1 CHIEF OF NAVAL EDUCATION AND TNG /
1 USA SIGNAL SCHOOL + FT. GORDON EDUCATIONAL TECHNOLOGY DIVISION
1 HQ ATC/XPTD TRAINING SYSTEMS DEVELOPMENT
1 USAISD ATTN: ATSIE-DT
1 US ARMY ARMOR CENTER ATTN: ATZK-TD-PMO
1 USA QUARTERMASTER SCHOOL DIRECTORATE OF TRAINING DEVELOPMENTS
1 US COAST GUARD ACADEMY /
1 USA TRANSPORTATION SCHOOL DIRECTORATE OF TRAINING + DOCTRINE
1 USA INFANTRY SCHOOL LIBRARY /
1 USA INFANTRY SCHOOL ATTN: ATSH-I-V
1 US ARMY INFANTRY SCHOOL ATTN: ATSH-CD
1 USA INFANTRY SCHOOL ATTN: ATSH-DOT-LRD

1 USA INFANTRY SCHOOL ATTN: ATSH-EV
1 USA MP + CHEM SCH/TNG CEN + FT. MCCLELLAN ATTN: ATZN-PTS
1 USA MP + CHEM SCH/TNG CEN + FT. MCCLELLAN DIR, COMBAT DEVELOPMENT
1 USA MP + CHEM SCH/TNG CEN + FT. MCCLELLAN DIR, TRAINING DEVELOPMENT
1 USA MP + CHEM SCH/TNG CEN + FT. MCCLELLAN ATTN: ATZN-MP-ACE
1 USA INSTITUTE OF ADMINISTRATION ATTN: RESIDENT TRAINING MANAGEMENT
1 USA FIELD ARTILLERY SCHOOL MORRIS SWETT LIBRARY
1 USA INSTITUTE OF ADMINISTRATION ACADEMIC LIBRARY
1 USA WAR COLLEGE ATTN: LIBRARY
1 USA ENGINEER SCHOOL LIBRARY AND LEARNING RESOURCES CENTER
1 USA ARMOR SCHOOL (USARMS) ATTN: LIBRARY
1 ORGANIZATIONAL EFFECTIVENESS CEN + SCH ATTN: LIBRARIAN
1 US ARMY INTELLIGENCE CENTER + SCHOOL ATTN: ATSI-TD
1 US ARMY INTELLIGENCE CENTER + SCHOOL ATTN: ATSI-RM-M
1 US ARMY INTELLIGENCE CENTER + SCHOOL ATTN: ATSI-TD-LD
1 US ARMY INTELLIGENCE CENTER + SCHOOL ATTN: ATSI-CD-CS-C
1 US ARMY INTELLIGENCE CENTER + SCHOOL ATTN: ATSI-DT-SF-IM
1 DEPARTMENT OF THE AIR FORCE AIR UNIVERSITY LIBRARY (ATC)
1 HQ TRADOC TRAINING DEVELOPMENT INSTITUTE
2 BRITISH EMBASSY BRITISH DEFENCE STAFF
2 CANADIAN JOINT STAFF
1 COLS (W) LIBRARY
1 FRENCH ARMY ATTACHE
1 AUSTRIAN EMBASSY DEFENSE, MILITARY AND AIR ATTACHE
3 CANADIAN DEFENCE LIAISON STAFF ATTN: COUNSELLOR, DEFENCE R AND D
1 ROYAL NETHERLANDS EMBASSY MILITARY ATTACHE
1 CANADIAN FORCES BASE CORNWALLIS ATTN: PERSONNEL SELECTION
2 CANADIAN FORCES PERSONNEL APPL RSCH UNIT
1 ARMY PERSONNEL RESEARCH ESTABLISHMENT
1 NETHERLANDS EMBASSY OFFICE OF THE AIR ATTACHE
6 LIBRARY OF CONGRESS EXCHANGE AND GIFT DIV
1 DEFENSE TECHNICAL INFORMATION CEN ATTN: DTIC-DDA-2
140 LIBRARY OF CONGRESS UNIT DOCUMENTS EXPEDITING PROJECT
1 US GOVERNMENT PRINTING OFC LIBRARY, PUBLIC DOCUMENTS DEPARTMENT
1 US GOVERNMENT PRINTING OFC LIBRARY AND STATUTORY, LIB DIV (SLL)
1 THE ARMY LIBRARY ATTN: ARMY STUDIES SEC
3 ROYAL ARMY EDUCATIONAL CORPS CENTRE ARMY SCHOOL OF TRAINING SUPPORT

NUMBER OF ADDRESSEES 222

TOTAL NUMBER OF COPIES 402

GPO 601-700